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Responding to a widely expressed discontent about college teaching shared by students, faculty and administrators, representatives of national professional and higher educational associations formed a committee to study means of revitalizing and reorienting instruction. Each contributor in Volume II, selected for his outstanding teaching skills in the sciences, examines current trends in teaching in his discipline, offers a critical review of the principal methods used, and provides pertinent bibliographical references. In his Introduction, Russell M. Cooper notes the impossibility of prescribing any single method of improving teaching and calls for reflection and self-criticism by the teacher. All of the papers discuss specific aspects of college teaching: graduate assistants, students who are science and nonscience majors, laboratory procedures, use of new technology, innovative practices, and do's and don'ts of teaching. Contributions cover: "The Art of Teaching Science" by Morris H. Shamos; "A Path to Relevant Teaching" by Garrett Hardin (dealing mainly with biology); "The Earth Sciences" by Sheldon Johnson; "The Teaching of College Chemistry" by W. T. Lippincott; and "The Beginning Teacher of College Mathematics" by R. L. Wilder. An extensive bibliography is included. (JS)

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THE QUEST FOR RELEVANCE

Effective College Teaching

VOLUME II

THE SCIENCES

AMERICAN ASSOCIATION FOR HIGHER EDUCATION March 1969

U. S. DEPARTMENT OF
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THE QUEST FOR RELEVANCE

Effective College Teaching

FOUR VOLUMES

VOLUME II

THE SCIENCES

Prepared by the

AMERICAN ASSOCIATION FOR HIGHER EDUCATION

Washington, D. C.

March 1969

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PREFACE

This volume grows out of a deepening concern of leaders among national professional societies and members of the American Association for Higher Education (AAHE) for improving quality and increasing relevance in college teaching. Responding to a widely expressed discontent among students and unease within the teaching profession, the AAHE assumed responsibility for calling together representatives from professional organizations to discuss the means of revitalizing and reorienting instruction in colleges and universities.

These representatives, under the chairmanship of Russell M. Cooper, Dean of Liberal Arts, University of South Florida, formed the Joint Committee on College Teaching (JCOT). The committee has included representatives from the following professional associations:

American Association for the Advancement of Science
American Association for Higher Education
American Association of Junior Colleges
American Chemical Society
American Council on Education
American Council of Learned Societies
American Economic Association
American Historical Association
American Institute of Biological Sciences
American Institute of Physics
American Political Science Association
American Psychological Association
College English Association
Conference Board of the Mathematical Sciences
Modern Language Association of America
U. S. Office of Education

The Advisory Committee for the study, listed below, was drawn largely from representatives of that group of organizations.

The completion of the book envisioned by the Joint Committee on Teaching has been made possible by a grant from the U. S. Office of Education with the AAHE serving as administrative and fiscal agent.

The contributors to this book were selected because of their vivid conceptions and demonstrable skills in teaching. Collectively, they do not offer a comprehensive representation of all disciplines. In fact, as originally divergent views on the rationale and scope of the book coalesced into a consensus, a clearly interdisciplinary overtone developed despite a format suggesting otherwise.

This work is divided into four volumes, but all volumes use the same preface, introduction, and general bibliography. The first three examine college teaching as perceived by some outstanding teachers representing the humanities (Volume I), the sciences (Volume II), and the social sciences (Volume III). In each volume an outstanding teacher discusses an entire area of study. Additional teachers of note, with full freedom to take an interdisciplinary stance, discuss the area with particular reference to their own disciplines. Each contributor to the first three volumes was asked to examine current trends in teaching in his area or discipline, to offer a critical review of the principal methods in use, and to provide pertinent bibliographical references.

The fourth volume treats, first, of matters of instruction which may be regarded as characteristic of effective teaching in all disciplines, with special attention to modern teaching aids (increasingly regarded not as incidental adjuncts but as essential to optimal learning), and the evaluative aspects of the teaching-learning process. This volume treats, second, of matters pertaining to the place of the teacher in his university and his community and of his responsibilities to them. It discusses the manner in which universities are organized administratively and in general terms discusses the regulations, communications and practices which are found on campus.

This book is intended for independent reading and as a basis for seminar and workshop discussion. Selected bibliographies are provided to encourage further exploration of knowledge of the art and craft of teaching. The book is designed not merely to communicate the personal experience of the authors but also to reflect the range of research and literature on college teaching.

Improving college teaching is certainly not a neglected subject. A long list of publications could be given, and many are included in the bibliography. The AHE (now AAHE) itself published "New Perspectives on Teaching the Disciplines," in Current Issues of Higher Education, 1962. It contains papers presented at AAHE's 17th National Conference on the teaching of the social sciences, geography, English, fine arts, and other subjects. Other publications that might be mentioned include these:

Wilbert McKeachie's Teaching Tips is a guidebook for the beginning college teacher (George Wahr Publishing Co. 1965).

Improving College and University Teaching, the quarterly edited by Delmer M. Goode for many years has delivered a broad range of short articles.

Improving College Teaching, edited by Calvin B. T. Lee and written by teachers and administrators, covers a wide variety of subjects and innovations.

The Importance of Teaching: A Memorandum to the New Teacher, is a guide to self-examination for those entering the profession.

Teaching in a Junior College, by Roger H. Garrison, deals with problems peculiar to junior and other kinds of 2-year colleges.

The Graduate Student as Teacher, prepared by Vincent Nowles, Kenneth Clark, and Miriam Rock reports a project at the University of Rochester.

Little in the literature on college teaching is prepared from the standpoint of the disciplines. Much that has been produced is general. It is to this deficiency that the present work is directed. At a period when it may seem perilous to write anything concerning higher education in the United States, the contributions in this work have been assembled with the conviction that all dedicated teachers are seeking ways of improving their teaching and of providing relevant subject matter as they challenge their students. It is the hope of those responsible for the work that it will be helpful to all college teachers and especially to those entering the profession.

Robert G. Bone
Project Director

Advisory Committee

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Maxwell H. Goldberg, Pennsylvania State University
Harold L. Hodgkinson, University of California, Berkeley
Arthur H. Livermore, American Association for the Advancement of Science
Paul L. Ward, American Historical Association
Winslow R. Hatch, Division of Higher Education Research, U. S. Office of Education.

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INTRODUCTION: THE COLLEGE TEACHER TODAY

by Russell Cooper*

> "I will do such things, -
> What they are, yet I know not; but they shall be
> The terrors of the earth! -- King Lear

At a time when inarticulate fury and a deep sense of betrayal are being translated into irrational violence on American campuses, it behooves the teaching profession to consider seriously the inadequacies and lapses of which it stands accused. Under the best of circumstances, teachers should be eager and active in searching out ways to improve their performance. Now, more than ever before, the public at large and the young in particular pose penetrating questions for institutions of higher learning. Teachers are called upon to defend the relevance of the subject matter they offer, to adopt new styles and techniques in teaching an ever-increasing number of students with varying backgrounds and disparate expectations, and to consider the influence, actual and potential, of higher education upon the social problems of the day.

In the quieter past, the home, the church, and to a degree industry have been dominant influences on the culture and mores of the nation. Now, institutions of higher learning find themselves closer to the center of the stage than ever before. An inescapable by-product of this new eminence and influence is responsibility for ensuring relevance in subject matter, challenge and intellectual excitement in providing and guiding learning experiences, and enlightening leadership in the development and improvement of society.

Ironically, at the very time when all components of society are demanding greater educational opportunity and college graduates with increased competence, willing and able to bring new order, justice, and human dignity to a world in chaos, much that the university has traditionally offered is scorned and rejected. At the very time the conscientious teacher is striving to present relevant concepts, information, and techniques effectively to rapidly multiplying numbers of impatient students, he must face vast amounts of new knowledge which should be sorted, assimilated, reorganized, and prepared for the classroom.

This volume has been written in the conviction that, while most teachers are well aware of the difficulties and satisfactions of effective teaching and share the assumption that there is no single exclusive method of excellent teaching, both the novice instructor and the senior professor can profit from a fresh and direct examination of the process of teaching and learning in higher education. Most academics concede that there is no such person as a "perfect" teacher and that any teacher who is genuinely content with his performance merely demonstrates that his goals were so modest it was possible for him to reach them. No responsible teacher lays claim to final truths which will guarantee perfection in the practice of teaching; nevertheless, many young teachers can learn much from those who have continued to learn and have been willing to test new ideas and to adapt those that proved successful. Veteran teachers can offer reliable suggestions concerning ventures likely to be productive and those likely to continue to lead to frustration and failure.

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*Dr. Cooper is dean, College of Liberal Arts, University of South Florida, and Chairman, Joint Committee on College Teaching.

Students know--and act upon their knowledge--that some teachers are more effective than others, not merely or even necessarily more learned but more resourceful in engaging and exciting students and launching them on intellectual adventures of their own. Students also often recognize more astutely than faculty colleagues or academic administrators that many teachers are at their best with particular kinds of students but either fail to challenge with other types or to be appropriately compassionate. The lackluster lecturer may be a deft and probing seminar leader; the brilliant and dramatic expositor may be the overbearing monologist who frustrates small-group discussion. Whatever his gifts or limitations, the teacher with a vocation must be alertly self-critical; he must seek continually for increased effectiveness in communication and intellectual engagement; he must check repeatedly and with painful honesty to ensure that the knowledge he endeavors to communicate and the skills he seeks to develop are, and are demonstrated to be, relevant to the time and to the students.

This work has been designed primarily for those newly embarked upon a teaching career whether as neophyte faculty members at the end of graduate preparation or as teaching assistants in a university. But even the veteran teacher, like the admirable Clerk of Oxenford, with a mind open to fresh suggestion, should find much in these pages to inspire reflection and experimentation. Individual readers may be more interested in some sections than in others; however, a reading of the whole book should repay the effort, as it sets the task of teaching in full perspective.

This work reflects a deep and abiding common concern among leaders of national professional societies for the improvement of quality and the insurance of relevance in teaching in their several fields. If it succeeds in stimulating teachers to improve the practice of their art and craft and sustains them in their efforts, all those who have contributed to it will feel richly rewarded.

THE ART OF TEACHING SCIENCE

by Morris H. Shamos*

INTRODUCTION

The Teacher

With few exceptions the beginning college teacher in science is a graduate student, most often a doctoral candidate. At least this is true of the universities that offer graduate programs in science. In institutions that have no graduate programs (e.g., junior colleges) the beginning science teacher may be a part-time graduate student in a nearby university, or more likely he will have had previous teaching experience elsewhere. Very few college teachers of science have only the bachelor's degree and no graduate work (either completed orin progress) in their subject areas.

Characterizing the beginning college teacher in science as a graduate student may come as a surprise to some, particularly to those who have never regarded the teaching assistant in this light. Because of the nature of their duties many teaching assistants do not feel themselves truly a part of the teaching profession--and in many departments they are not thought of as teachers in the usual sense. Nevertheless, this sort of appointment gives them their first exposure both to some form of teacher-student relationship, however tenuous it may seem, and to a teacher-department relationship. Their attitudes about teaching, in fact, their overall impressions of the academic structure, are often crystallized during this experience. Some become strongly motivated by it; others may be just as strongly repelled from teaching careers as a result of unhappy experiences as teaching assistants.

Normally, one thinks of the beginning college teacher as a recent Ph.D. who has received his first professional academic appointment, generally in the rank of instructor or assistant professor. While it is true that such persons are recognized as full-fledged faculty members, whereas graduate teaching assistants are not, one should bear in mind that most of the former were in the ranks of the latter just prior to their full-time academic appointments. There may be a lag of a year or two, while serving as post-doctoral research fellows, but it is quite clear that practically all who enter the college teaching profession in the field of science had their first taste of it while serving as teaching assistants--and that such service, in point of time, was but recently removed from their first regular faculty appointments.

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*Dr. Shamos is chairman, Department of Physics, New York University, and immediate past president, National Science Teachers' Association.

Most beginning teachers are young, barely older than their students, to whom they probably relate better than they do to most of the senior members of their departments. Their titles vary: Teaching assistant, graduate assistant, teaching fellow, or occasionally lecturer or instructor. The last two generally imply full-time teaching duties; the others are part-time assignments to allow for graduate study. The past two decades have seen a slight departure from this practice. Because of the availability of Federal funds for graduate fellowships and research assistantships in the sciences some of the most promising students complete their graduate work without having to teach, and hence begin teaching somewhat later in their careers and usually at a higher academic level. This change creates a special problem, for it means that such persons must assume a greater degree of responsibility and authority in their first teaching position than those the regular graduate assistants assume.

The duties of the latter group vary somewhat according to discipline and institution. In those disciplines in which large laboratory sections are the practice (e.g., biology and chemistry) the experience of a graduate assistant may be limited to assisting a senior member of the department in the laboratory. (Sometimes these sections are large enough to require several graduate assistants.) His work in the laboratory, plus grading laboratory reports and examination papers, may be the only exposure to students that such a graduate assistant will have. This means that he may acquire no significant teaching experience, involving full intellectual contact with students until his post-doctoral years.

Some departments, notably in physics, have relatively small laboratory sections in their introductory courses and generally have small discussion sections as well. In such departments the graduate assistant has a more challenging assignment, since he is often placed in charge of one or more of these sections. This has mixed blessings. Not all first-year graduate students respond equally well to the sort of challenge in which one is faced with the direct responsibility for a group of students , including an evaluation of their performance. While the curriculum, text, examinations, and the like, are generally the responsibility of a senior faculty member, who supervises the work of the teaching assistants, they nevertheless have the sort of contact with students, particularly in recitation sections that is very close to a true teaching experience.

Being on the "firing line" in this way has the advantage of maturing some teachers very rapidly, although all graduate assistants may not adapt to it readily and may perhaps be somewhat unfair to the students. In general, those graduate assistants who seek academic careers and have a genuine interest in teaching, profit most from such an abrupt plunge into a teacher-student relationship. Every department can point to a few of its graduate assistants who show promise of becoming exceptional teachers. For such assistants some measure of independence in the classroom is probably the best training. Others may require a more gradual introduction to teaching. Whatever the case, until one has had the responsibility for guiding a group of students through a major segment of a course he cannot be said to have truly begun his college teaching career.

Ultimately, a regular member of the faculty must assume primary responsibility for a given course in his department. Normally, he will be of professorial rank, although in some departments instructors and lecturers may also be given such assignments. If the course is lecture-laboratory the faculty member in charge generally does the lectures and determines course routine, leaving the laboratory and possibly discussion sections to junior members of the staff, usually to graduate assistants. How much independent judgment he allows them in carrying out their duties depends upon the department and, to some extent, upon the kind of laboratory. In large laboratory sections, for example, graduate assistants may serve as little more than "trouble shooters" and graders.

The duty of the graduate assistant, and hence the extent to which he becomes involved in teaching largely depends upon how his particular department views theposition. In the past some science departments regarded it as merely a means of supporting their graduate students; others frankly viewed it as a source of inexpensive help. But many departments looked upon teaching as an essential part of graduate training in science, on the dual grounds that teaching a subject helped one to learn it and that it served to initiate prospective academic scientists into what was at one time considered a major function of academic life, namely teaching. In fact, some departments insisted that every doctoral candidate have some teaching experience during his graduate career.

Customs have changed in the past two decades, partly because of increased numbers of graduate students in the sciences, partly because of increased research funds, and partly because of a greater concern for the welfare of the undergraduate.

The larger number of graduate students makes it impossible for many departments to afford all students an opportunity to teach. This development is not to be regarded as necessarily unfortunate for it means that preference can be given to those who are primarily interested in academic careers, leaving those who are not interested in teaching to be supported by research funds, fellowships or other sources. Another reason for the preference is the increased sensitivity of science departments to the complaints of undergraduates about the teaching skills of graduate assistants. Thus, the graduate teaching assistantship in most science departments is no longer regarded primarily as a means of supporting graduate students or of securing cheap labor. Instead, there is a growing tendency to look upon it as part of the training of the graduate students who profess an interest in teaching and who also appear to be suited to it. This is not to suggest that the millennium has arrived--that teaching assistants in the sciences are being accorded full faculty privileges and given all the help they need to develop their teaching skills. Far from it. As Wise (1) points out, except for a few institutions the situation is still rather deplorable. Yet the trend is encouraging.

It is not easy to achieve the best balance in a department between teachers and research assistants as both positions compete for similar talents. The teaching assistantship was once regarded as a prestigious appointment by most graduate students, but the research assistantship has largely supplanted it as a more direct path toward the doctorate. The cutback in research funds during the latter half of 1968 had the effect of suddenly increasing the number of applicants for teaching assistantships. Various departments are experimenting with ways of resolving this dilemma, as well as with the problem of how to make the teaching experience of graduate assistants more meaningful than it has been in the past. It is hoped that new ways will be found to make the work of such assistants in the sciences much more stimulating and rewarding to all concerned with teaching--the graduate assistants, the senior faculty, and the undergraduates.

There are several obvious ways of achieving more effective involvement of teaching assistants in the educational process. One method, which is used by a few science departments, is to bring all new teaching assistants to the campus several weeks prior to the opening of classes for a series of briefings, discussions with senior faculty members and possibly a short course or seminar series devoted to teaching problems and techniques. Another method is to require that all new assistants take what is, in effect, an "in-service" teacher-training program during their first semester in residence. Such a program might consist of the same elements mentioned above, that is, briefings, discussions and methods seminars, plus the added features of perhaps involving members of the faculty of education and observing and evaluating the teaching assistants on their effectiveness as teachers. Needless to say, if such a program is attempted, the normal duties of the teaching assistants during this period should be reduced accordingly.

Still another approach is to require each teaching assistant, or at least those who profess an interest in academic careers, to take overthe course lecture for a day or two toward the end of his first year in the department. Such experience is invaluable to the beginning teacher, for it not only stimulates him but provides both the teacher and senior faculty a means of assessing his potential as a member of the teaching community. There are problems with this approach, of course, particularly thepossible resentment of students in the course to having inexperienced lectures assigned to them. Hence, if used at all, this method requires great care and diplomacy on the part of the senior faculty.

The Students

There are three main categories of students who enroll in science courses in our colleges:

(a) Pure science majors, most of whom regard their undergraduate preparation as a form of professional education even though they are found mainly in liberal arts colleges. A large proportion of these students plan to go on to graduate work, as many as two-thirds or more in some fields. A few go into high school teaching and the rest go into industry or government laboratories. For the most part the undergraduate science curriculums for majors are designed to prepare them for graduate work and professional careers.

(b) The "applied science" students, who are required to take certain science courses as part of their pre-professional training in a science-related field. These include engineering students, premedical and predental students, other pure science majors, mathematics majors, and the like. Very often these students are placed into the same courses as the science majors in a given department; in some cases special courses (or special sections of a course) are designated for one or more of these groups. There are cogent arguments for both systems, as is pointed out later.

(c) The non-science students, who generally take science as part of their distribution requirements, and who, more often than not, are unhappy about the requirement. This group includes education and commerce students, and in a typical university it comprises more than 90 percent of all students enrolled in the introductory science courses. In some institutions these students are required to take the regular departmental courses designed for science or applied science majors. In most colleges, however, special courses are offered for this group, a practice which appears to be growing and which, in recent years, has provoked considerable thought and attention among science faculties and others responsible for formulating educational policy in American colleges.

Those for whom college science is most meaningful are naturally the students who regard it as part of their "professional" training. These include the pure science majors and what have been termed "applied science" or "science-related" majors; that is, the engineering, premedical, predental, and similar majors. Usually, much more detailed information and depth of understanding can be expected of these students than one could reasonably expect of non-science students. This is certainly true of majors, who are after all potential colleagues, and perhaps somewhat less true of the science-related group. The least common factor that sets both groups apart from the non-science students is, of course, a professional commitment to some branch of science, if not an intellectual one.

The Courses

The beginning college teacher usually faces his most challenging assignment in the introductory courses, and particularly in those taken by the non-science students. In fact, teaching an introductory course is probably the most difficult task of any college science teacher. In most departments the beginning teacher (graduate assistant) is assigned all his teaching duties in such courses. In the rare instance that a new graduate assistant is given an upper division assignment, it is invariably as an assistant in a large laboratory section in which he has little direct responsibility. Hence the following discussion will be limited to the lower level or first-year courses.

Every science department has an introductory course designed for the "serious" student, meaning departmental majors and in many instances the students in science-related fields. Some departments have two such courses, one for departmental majors and the other for the group (b) students. They are more likely to offer two courses in physics and chemistry than in biology or geology. In addition, there may be other introductory courses for special groups of students (e.g., physics for engineers or chemistry for nurses). While course offerings today are probably a good deal less fragmented than they were two or three decades ago, one still finds departments that offer a number of introductory courses, each designed for a particular group of students and differing slightly from the others.

From the point of view of the beginning teacher there may be important differences among these courses. The difference lies chiefly in the outlook of the students. For example, the interaction between a graduate assistant and a prospective physics major enrolled in an introductory course in the physics department might be quite different from the interaction between the assistant and a premedical student or engineering student enrolled in the same or other first year physics courses. In the former case there is a stronger sense of identity with both the student and the course material. In general science majors tend to relate well to graduate assistants in their own disciplines, just as they do to their fellow majors. The identification stems from a common professional interest and probably in part from the realization that the time devoted to such courses and students will directly benefit the profession.

Courses that are not designed for majors are usually regarded as "service courses," a term that somehow carries a pejorative connotation. No science department likes to consider itself primarily involved in providing service courses; there is something impermanent about the idea. Yet most departments are called upon to provide such courses because the number of non-majors enrolled in a given science department at any one time usually far exceeds the number of majors, as is shown earlier in relation to non-science students.

As to the differences in course content between those designed for majors and those designed for special science-related groups of students, it may be no more than a matter of emphasis. For example, an introductory physics course designed for engineering students might differ from the conventional course only in stressing certain examples and subject matter of special interest to engineers (e.g., statics, strength of materials), and in using engineering units rather than metric. On the other hand, the difference is sometimes fundamental. Frequently, the introductory physics course for majors or engineering students requires calculus as a prerequisite, whereas a course for liberal arts students generally would not require it. This means that there is not only a different emphasis but also a different basic approach. The graduate assistant feels more confortable when he is involved with the calculus-based course, for it is easier to teach physics when one is free to use appropriate mathematical techniques. It is often the case in chemistry, since the laboratory course for majors requires a stronger mathematical background than the corresponding course for non-majors. It is rarely the case in biology or geology, since the introductory courses are usually open to all students, majors and non-majors alike. Thus the teacher in these courses must cope with a much wider range of student interest and motivation, a situation that is far from ideal.

In the final group of courses are those designed specifically for non-science students, the largest bloc of students on any university campus. Here too, some departments make no distinction between these students and their own majors, as far as the introductory course is concerned. The theory is that the best way for them to help a non-scientist appreciate a given scientific discipline is to expose him to it in the same way as they do one who is preparing for a career in that discipline. While some non-science students apparently do benefit from the rigor and professional orientation of a course designed for majors, most do not, and on the whole the theory has been widely discredited. Most colleges therefore offer one or more special courses for their non-science students.

These range from simplified versions of the regular departmental courses to composite courses such as physical science, or integrated courses that in principle cut across departmental lines. The latter type of survey course has had a checkered history. It is by far the most difficult kind of science course to teach because very few teachers feel equally at home in several science disciplines. As a result, when a single person tries to teach such a course, he tends to stress that area with which he is most familiar; that is, his own discipline.

To overcome this problem, departments sometimes offer such courses as a "team teaching" effort, different segments of a course being taught by specialists from the various disciplines. This approach has not proved very successful either, for it depends so much upon how the team members view the purpose of an integrated course and how well they work together. There are also logistic problems for the staff associated with such a course, since only one team member actually teaches at any given time. Scheduling for such courses is easier, for example, in institutions operating on the quarter system than those on the semester or trimester systems.

Not all courses for non-science students offer laboratory experience. Some departments apparently believe that the limited experience provided for in the short time available cannot be very meaningful and that the time might be better spent in other ways. This is not yet a widespread practice, but the feeling is growing that the routine laboratory exercises characteristic of standard introductory courses are not the best means of demonstrating the experimental approach to such students. Most academic scientists believe that the laboratory is an essential part of science education, but many also believe that the non-science student deserves special attention, in regard to both course design and laboratory experience.

THE GOALS OF SCIENCE EDUCATION

Scientific Literacy

One of the strangest paradoxes of our times is the great gap between the practice and the teaching of science. This may be a scientific age by some standards, but certainly not if judged by the scientific sophistication of the general population. Incongruous as it may seem for a civilization that is go greatly dependent upon science, Americans are on the whole scientifically illiterate.

Despite the enormous strides the country has made in scientific knowledge, science teaching remains largely an art. Evidently teachers have not yet discovered either the proper motivating factors or the pedagogical techniques (or both) that are needed for developing true scientific literacy. The scientific community has produced a highly ordered body of knowledge and developed a methodology that appears to be reasonably successful in guiding it toward a better understanding of nature; yet except for selected groups of students teachers have not succeeded in imparting this knowledge to others in a meaningful way.

Although these two groups are in a sense "captive" students, in the past decade or so concern has been voiced in some quarters that the traditional courses offered them have not kept pace with new developments in the sciences. In an effort to improve science courses and curriculums in the colleges eight college science commissions have been established in recent years.(2) These are independent, ad hoc organizations, which have two primary goals: To update the content of undergraduate courses and to bring to bear on them the same sort of inquiring attitude that is characteristic of creative research. The activities vary among the commissions, but in general they range from pre-professional education to general education for non-science students. An instructor or department considering a course or curriculum revision would be well advised to examine the reports of the appropriate commission before making any changes.

While the commissions do maintain an interest in the non-science student, he is not their primary concern. His problem has therefore not been tackled in a fully organized fashion. Yet it is in a way the most pressing problem in science education today. More is said later on the question of curriculum development for non-science students.

Practically every college requires its students to take some science as part of a liberal education, whether ornot they are interested in this phase of man's intellectual activity. In the past it was taken for granted that science was one of the "cultural imperatives" of a college education. Today one hears serious challenges to this practice on the ground that if the science that is presented to non-science students makes so little impact on them, why should it be required? This criticism has forced the academic community to reexamine the goals of education for the non-science student.

Why Teach Science?

Why do schools teach science to all students? Clearly they do not teach it only to produce scientists and engineers, for there are too few of them to justify the massive effort in contemporary science education. Schools insist that all students be exposed to science, yet more than 90 percent of all students are not science bound, nor will they in their adult lives have any direct contact with science in a formal way. Hence one cannot reasonably argue that compulsory science education satisfies a practical need of society, just as one cannot justify most of what is taught in the liberal arts on utilitarian grounds.

Thus the purpose of science education (for non-science students) must be primarily intellectual rather than utilitarian. Schools teach science, as they teach most disciplines, in fact, to acquaint students with the world in which they live--with the aesthetic as well as the real world. How they ultimately cope with the real world (intellectually) depends largely upon how comfortably they fit into it, which in turn means how well they appreciate man's efforts to understand and control nature.

It follows that the main goal of science education for non-science students should be to provide them with the sort of background they will need to function as informed, literate adults in modern society. This is much easier said than done, as must be evident from the many decades of fruitless effort in this direction. If one confines himself to specific objectives the task is a good deal simpler, except that those objectives which one can easily test are almost certain to fall in the cognitive domain and are very likely to be trivial. The reason is obvious: it is much easier to test for factual knowledge than for intellectual skills such as analysis and synthesis. And the latter, in turn, are easier to evaluate than are the sort of long-range objectives that relate to scientific literacy. Such objectives fall mainly in the affective domain, as may be seen by the following example.

In 1966 the Educational Policies Commission of the NEA issued a report which sought to define the "spirit of science" and to urge schools to promote understanding of the values on which all science is based. The report, which was the product of a group of distinguished scientists and educators, lists the following values underlying science:

" 1. Longing to know and to understand.
2. Questioning of all things.
3. Search for data and their meaning.
4. Demand for verification.
5. Respect for logic.
6. Consideration of premises.
7. Consideration of consequences." (3)

Note that the values do not refer specifically to science, but clearly would be desirable outcomes of any educational program. One could wish for little more than to have such values guide the thoughts and actions of educated men generally. The fact that these attitudes are particularly evident in thepractice of science is sometimes given as an argument in favor of some science education for all.

The general nature of these statements should also be noted. They reflect attitudes or values, as do all substantive goals of liberal education. To these might be added such obvious objectives as...appreciation for the nature of science, or...understanding of the role of science in man's intellectual development and so on. All are affective goals, for which teachers have no simple means of testing, nor do teachers know how to design curriculums that may lead to such objectives. This point cannot be emphasized too strongly. Specifying educational goals is relatively easy, whether they be cognitive or affective goals. Designing a curriculum that promises to achieve these goals is much more difficult--and more difficult still is the designing of effective test instruments to measure the achievement of these goals, particularly in the affective domain.

The problem is further complicated by the fact that the primary goal one seeks when confronted with the question of scientific literacy is a long-range rather than an immediate objective. Hence testing the effectiveness of a given curriculum in regard to its contribution to general scientific literacy in adults is clearly very difficult, if at all possible in an objective fashion. In view of these difficulties, perhaps all that can be done when designing a curriculum for non-science students is simply to keep in mind the lessons of the past. It is well known, for example, that non-science students tend to avoid quantitative science courses in favor of the more qualitative or descriptive courses. Thus, where a free choice is permitted, they favor biology and geology over physics and chemistry, with physics invariably the last choice.

The Role of Mathematics

This tendency of students to shy away from mathematics, even when it is used merely as a tool, must be counted as a major reason why students seek to avoid certain science courses. Most students do not fully appreciate either the power of mathematics as a system of logic or the nature of its role as the language of science. In face, it is a serious failing of almost all academic science that mathematics is portrayed primarily as a tool for solving problems in science. This is the popular notion,one that is harmful both to the cause of science and to mathematics.

The physicist, P. W. Bridgman, once pointed out..."that the fundamental human invention is language, and that we owe the progress of the race to it more than to anything else." In a similar sense, mathematics is also a language, and the progress of science is more indebted to it than to anything else.

Mathematics is the language of science, the only language available by which statements about nature can be combined according to formal, logical rules; a language which not only allows one to describe in precise terms the world about him, but also provides him with a means of dealing with the descriptions that may lead to new knowledge of the universe. It is an essential part of the structure of science, not simply an accessory or tool. Physics, for example, could not have developed to its present stage without mathematics--and the life sciences will not achieve the same level of sophistication until they have established a firm mathematical foundation. This should be borne in mind whenever one reflects on the goals of science education, for surely one of the goals ought to be a clear understanding of the role of mathematics in the scientific enterprise.

Trends in Curriculum Development

The major problem in contemporary science education is to provide meaningful courses for non-science students. There has been no major effort along these lines that could compare with the massive curriculum development projects in science for the elementary and secondary schools during the past decade, practically all of which were funded by Federal agencies. Instead, with one or two exceptions such as the PSNS Project,(4) curriculum development in college-level science has been on a much more limited and individualized scale. Descriptions of some of the programs may be found in the newsletters published by the several college commissions. The PSNS Project, for example, grew out of a number of conferences sponsored by the Commission of College Physics, with the cooperation of the Advisory Council on College Chemistry. Others are described from time to time in the various journals devoted primarily to science teaching (e.g., American Journal of Physics, Journal of Chemical Education,). But perhaps the best guides to current trends in course development are the texts and supplementary readings that have been published in recent years.

For the most part, the texts and supplementary materials that depart from theusual format tend to concentrate on a few major topics, to go into these in greater depth, and to stress the development and structure of the discipline rather than minute details. The choice of topics may differ, reflecting as they do the designers' views of the course, but the common element is readily discernible: an emphasis on ideas rather than on pure factual knowledge. This is particularly evident in the supplementary reading materials presently available, especially the paperbacks, many of which deal with only a single topic. The fact that the great ideas or conceptual schemes of science are total abstractions and that many of them require stretching one's imagination beyond the limits of "common sense," appears not to trouble the non-science student as much as solving problems or committing to memory such factual material as systems of units, conversion factors, classification systems, and so forth.

By playing down the routine problem solving and pure memorization, which after all are really unimportant to anyone but professional scientists or to those preparing for careers in science, the course makes more time available for dealing with substantive ideas. The non-science students apparently find such courses much more palatable than the older courses. This is not to say that mathematical demonstration must be completely abandoned. On the contrary, some of the new courses maintain reasonable mathematical rigor but simply minimize the problem-solving skills normally required of students in the physical sciences.

Thus, the general trend appears to be away from the survey course and toward in-depth focus on one topic, or perhaps a few topics at most. There is also a discernible tendency to include more history of science in such courses, somewhat reminiscent of Conant's famous case history techniques.(5) This is not suggested as a substitute for science proper but rather as a supplement to it--one that somehow appeals to students generally and that might be considered by the new teacher as an effective means of gaining student interest. Where term papers or reports are assigned in such courses it is often useful to suggest that students write these in the history of the subject, rather than on some contemporary phase. Since the history of science is largely descriptive, students usually feel more comfortable with it and find doing such a paper more of an enjoyment than a chore.

TECHNIQUES OF TEACHING SCIENCE

Introduction

There is a characteristic difference between the basic technique of teaching science and that used in teaching almost any other academic discipline, namely, the extensive use of demonstration. Whether demonstration is used in the classic sense of lecture demonstrations, or with chalkboards and other visual aids, it is striking how much more science teaching depends upon the visual sense than upon the auditory. Even the tutorial or discussion sessions commonly used in certain disciplines (e.g., physics) are demonstrative in the sense of developing skills in problem solving or reinforcing the students understanding of the subject matter. It is virtually impossible, when teaching science, to communicate with students by the spoken word alone. One always needs some means of visual exposition. This sometimes presents a problem in institutions that have common classroom faciltiies; a room suitable for a course in literature or history may be wholly unsuited for a science course because of inadequate board space. Room assignment clerks do not always appreciate this difference and usually must be educated to it by the uncompromising demands of the science faculty.

Good facilities for science teaching are, by comparison with other disciplines, far more costly in both space and money--a fact that does not go unnoticed by non-science departments in the competition for university budgets. The additional space is required mainly for the laboratories, with their attendant stockrooms and service shops (e.g., machine shops, electronic shops, and glass working shops). The higher cost is accounted for largely by equipment, supplies, and the technicians needed to staff the various shops and stockrooms.

For the science major there appears to be no satisfactory substitute for direct laboratory experience. There are differences of opinion on the relative merits of "even-front" laboratories (all students doing the same experiment during a given lab period) vs. individualized laboratories (each student or student pair working on a different experiment and rotating each week from one to another). The individualized laboratory has the advantages of providing a greater diversity of experiments for a given equipment budget and an opportunity to conduct open-ended laboratories. There are disadvantages for the instructor, of course, and in some science disciplines such a system may be quite impractical. However, there does appear to be a trend toward the individualized laboratory, particularly in physics, where laboratory equipmend tends to be fairly costly and where this has long been the practice in advanced courses.

As for laboratories for non-science students, the question remains open. Some teachers do not believe that the laboratory is an effective instructional technique for this group. Others, and these probably constitute the majority, believe that the laboratory is essential to teaching any science, but many would concede that new patterns must be found to make the laboratory a more meaningful instructional tool for non-science students.

The New Technology

Of all the new audiovisual aids that have come on the scene in the past decade or so, closed-circuit television holds the most promise for science education. Closed-circuit TV is solving one of the major problems of the large science lecture hall, namely, bringing the lecture demonstrations, regardless of size, close to every student in the class. This is accomplished by placing monitors throughout the lecture hall, usually suspended from the ceiling, and using one or two cameras at the lecture table. The one drawback at the moment is the lack of color, which may be very important for certain types of demonstrations, but color is probably not too far in the future. Closed-circuit TV may soon invade the laboratory as well. One can imagine, for example, that all the microscopes in a biology laboratory will be equipped in the future with individual TV cameras and monitors, as many research microscopes are today.

Many of the functions of slide and overhead projectors can be taken over by closed-circuit TV once a lecture hall has been equipped with monitors. An advantage of this system over the overhead projector, for example, assuming that color is not a critical factor, is that it can also be used to project opaque objects or materials. Thus, when properly installed, closed-circuit TV can replace all forms of still projection as well as provide close-ups of lecture demonstrations, and all convenient to the instructor. It takes little imagination to see this as the single visual aid system of the future, although its use today is still small compared with the move conventional visual aid devices.

The use of computer-assisted instruction and other "self-training" devices (e.g., programed texts) has not yet had much impact on science teaching at the college level. Some courses have been programed, and a few programed texts have appeared, buton the whole the academic community seems unwilling to experiment very broadly with the new educational technology. There is little doubt that in the development of skills (e.g., mathematical skills, problem-solving in physics or chemistry, classifications, morphology) educational technology can play a significant role. Hence the computer will no doubt become a routine adjunct to the classroom of the future. However, as is pointed out earlier, the truly important goals of science education are not simply skills, nor do they fall in the cognitive domain. This means that until science educators discover how to specify affective goals in behavioral terms, so that the resources of educational technology may be brought to bear on the problem, one cannot look to computer-assisted instruction as a panacea for science education, or even as providing a fresh path toward scientific literacy.

Examinations and Grades

It is sometimes said that for most students a college education consists mainly of sporadic preparation for examinations. There is a large measure of truth in the statement, for our educational system demands that teachers evaluate students in some way, and the so-called objective examination has become the major evaluative instrument on which course grades are based.

The trouble with objective examinations--and the sciences are perhaps more at fault here than most other disciplines--is that they test little more than a student's power of recall. The more objective an examination is, the more factual it is bound to be and the less its value as a means of measuring student understanding or appreciation of important ideas in science.

One can easily evaluate a skill, such as laboratory technique, by direct observation--or skill in problem solving by objective examinations. And it may be that for the science major the discipline fostered by such examinations is a valuable part of his professional training. Even this supposition is debatable, for not all students respond equally well to the pressure of written examinations, some of those who do not may be highly qualified for careers in science. Students deserve every possible opportunity to demonstrate their abilities by whatever means are necessary: Open-book examinations, where factual recall is unimportant, or personal interviews (oral examinations), laboratory reports, term papers, and the like. Since teachers are compelled to assign grades a useful technique is to permit each student to select from among several evaluative instruments (e.g., those listed above) a given number on which his grade will be based. While perhaps not ideal it is a fairer way of judging students than most systems that are used.

One might even challenge the entire concept of grades and grading systems, as many have done recently, for the evidence is that at best the correlation between college grades and success in later life is very tenuous.(6) However, until a better way is found to provide students with some measure of their progress and to compare them with one another, teachers must make the best of the present system. At the very least one should recognize the injustice of reading numerical grades too literally (e.g., distinguishing between 80 and 85), or of any grading system with gradations too fine to be meaningful.

The pass-fail option, which has now been adopted by a number of colleges, has proved to be a particular boon to the sciences insofar as the non-science student is concerned. Students who have a particular fear of science or who believe they will not do well in their science courses can, by electing this option, take their science in a relaxed frame of mind, without being overly concerned about their overall grade average since pass-fail courses are normally not included in the averaging process.

There are cogent arguments against the pass-fail system that deserve careful consideration. One is that it encourages academic laziness in students. Another is that a student's final record will not be a true indicator of his performance or ability if he elects the pass-fail option at every opportunity. To counter such arguments one might point out that at the college level it is more important that a student do very well in his major field (in which the pass-fail option usually is not permitted) than do only moderately well in all subject areas. Moreover, the modern concept of a liberal education leans more heavily on a meaningful exposure to several diverse branches of knowledge rather than mastery of each.

It seems to me that on balance the advantages of the pass-fail system, especially in science, far outweigh any problems it may create. One may hope that this practice will soon spread to all colleges and perhaps ultimately to the high schools.

The new teacher normally has little to say about the grading practices in his department or college. However, the entire question of evaluating student performance is so central to the education process that one can hardly think of developing new science curriculums (for non-science students, for example) without considering the forms of evaluation that might be used to assess the program. The new teacher, being so close to his own student days, can contribut a great deal to the dialog on this subject. He should make every effort to at least keep the issue alive in his department and persuade his colleagues that the problem warrants much consideration.

Showmanship

Teaching is an art. There is little that is "scientific" about it--even in the sciences. The new teacher in the sciences has contact mainly with beginning students, who may be science majors or not. These students are highly impressionable. They have not become jaded in the academic sense, particularly not in science. The image that the teacher creates in the minds of these students can be a major factor in his success with them.

In the theater one must be a showman to win his audience. There is something almost magic about the rapport that exists between the great performer and his audience. There is an element of showmanship in successful teaching as well. This does not mean that one must be a performer, although there are notable examples of highly successful lecturers in the sciences who plan their lecture-demonstrations as much for dramatic impact as instructional value. In fact, lecture-demonstrations in science, conducted as they usually are in large, impersonalized lecture halls, need something of this sort to maintain student interest at a high level, particularly for non-science students. Every science teacher should give some thought to the Thespian quality of his work.

But the beginning teacher rarely has this kind of opportunity to practice showmanship. His contact with students is more personal; hence his showmanship must be of a different sort. He establishes a rapport with students primarily through his sensitivity to their problems. It is no longer fashionable for college teachers to remain aloof from their students, and the beginning teacher must be particularly careful not to seem condescending to his students. Regardless of how he may feel about theintellectual or personality deficiencies of a group of students the mark of a good teacher is his ability to conceal these feelings and play the role of an understanding guide who is genuinely interested in the academic welfare of his students.

Establishing this kind of rapport with students is showmanship in the social and intellectual sense, rather than in the sense of dramatic performance. The relationship is charismatic rather than awe-inspiring. The beginning teacher can serve as a model of intellectual and personal development, one who is not far removed in age or outlook from most of his students. He can, if he is so inclined, guide students to emulate his own emerging career. However trite it may seem, those who serve as teaching assistants in the sciences have reached a certain level of recognition for their intellectual achievements, and may be able to inspire students to similar attainments..

The wise teacher will show that he understands both the power of formal instruction and the dynamics of contempory student life. He will make a studied effort to go beyond the classroom in his interaction with students--to make himself a part of both their intellectual and campus lives. To be successful at it he somehow must display the full range of his intellectual skill and curiousity, not only his knowledge of science. And this is probably best done in an informal social settingrather than in the classroom. It is time-consuming and may seem unproductive to the beginning teacher; but it is very important to students.

Some teachers have a flair for such a role. They can be firm yet gentle in their handling of students. They regard every question from a student as meriting a sincere, reasoned reply, regardless of how absurd or unintelligent the question may be. Ridicule is a self-defeating pedagogical device, one that has no place in the classroom. The new teacher should be very conscious of the respect and admiration that he commands; these will depend not only upon his mastering subject matter but also on his mastery of the art of teaching. It is an art worth cultivating by anyone who seeks an academic career.

IS SCIENCE RELEVANT

These are days of reassessment on college campuses. Students have become more vocal, more demanding with regard to their role in the academic community. It matters little that the more strident voices belong to a small minority; the whole academic world has been caught up in the pressure for change and the prevailing mood appears to be a willingness of faculties and administrations to experiment with new approaches to all sorts of academic problems.

What does this mean for the new science teacher? It means, first of all, a subtle change in the traditional teacher-student relationship, one that strangely enough often tends to bring the two closer together than they were in the past. The change is probably less obvious to the new teacher, who ishimself freshly removed from the student category, than to the old. Virtually all faculties have become sensitive to the mood for change. They (reluctantly) accept course and faculty evaluations (by students) as part of normal campus life--once the initial shock of the new student militancy has worn off. They more or less accept student representation on faculty committees and student participation in university governance.

Among the student demands one often hears a call for more relevant education--more relevant to the times, to social and political problems and to the students' lives. Whatever one may think of the merits of these demands it is proper to ask how the study of science may be considered relevant to the lives of students. I do not believe that relevancy should be the main, or even a necessary, criterion for liberal education. Nevertheless, since some students are raising this question, it is important that colleges try to answer it.

Obviously, the question has little meaning to science majors or even to students in science-related programs. Both of these groups see science as being directly related to their professional careers. Those for whom the question is most meaningful are the non-science students, many of whom believe that science is too remote from everyday life to warrant its inclusion among the "cultural imperatives". This group, as well as the majority of the adult population, sees science largely through its end products, through the technology that turns on its discoveries. We are literally surrounded by the material products of science. Our habits, our mode of life, our health, our ability to wage war or encourage peace--all are conditioned by advances in technology. These advances, moreover, result generally from specific needs of society. Against such a background it is not surprising that control of nature (technology) is so often confused with man's desire to understand it, which is the main goal of science.

What is most relevant to non-science students is technology. They are interested in the things they read about in the newspapers or see on television: Advances in medicine (or anything affecting their health), missiles, space travel, fluoridation, air and water pollution, or bomb testing, for example. They want to discuss the social and philosophical aspects of science, possibly because they can express opinions on these matters, whereas they cannot on science.

The danger in designing courses primarily responsive to the demand for relevancy is that the content may be so peripheral to the intellectual goals of science as to mislead students on the true nature of this branch of learning. Moreover few teachers of science can also represent themselves as being expert in such areas as philosophy or the social sciences. Unfortunately, the authority that a teacher represents in his special field is often extended by students to encompass all matters discussed in the classroom. Thus, there is a very real danger of transference of authority when discussing, for example, social problems having a scientific base.

One of the areas that non-science students seem to find particularly fascinating might better be termed "pseudo-science". They are interested in science fiction, in the occult, in parapsychic phenomena, flying saucers, alchemy, astrology, etc., in all the beliefs and practices which through the ages have existed on the fringe of science and were nurtured by man's ignorance and gullibility. One cannot easily dispose of these subjects by a wave of the hand. I would venture to say that in thepresent campus climate most students, given a choice between a course in science and one in science fiction, for example, would probably choose the latter.

This attitude is somewhat understandable, for to the average non-science student most of science probably seems strange and mysterious. Such students are not persuaded as much by the power of logical thought as by subject matters that permit free reign of the imagination. To some students this is what is meant by relevancy; that is, anything that is fanciful and "way out". For others, such topics hold some intrinsic interest, as they do for most people, but while they may be suitable topics for term papers these students would not insist that they should form the nucleus of a science course. At the same time, practically all students believe that the interaction of science and society should be a part of any science course designed for non-science students.

This is not to suggest that such topics have no place in the science curriculum. On the contrary, since they apparently do interest students, particularly non-science students, there should be a place for them in the curriculum. One simply should not permit such discussions to cloud the main purpose of science education, which is to portray the nature of the scientific enterprise. Furthermore, it should be made clear to students that in these areas the instructor is not necessarily any more expert than the ordinary educated adult. Studentshould realize that scientists can also have a social conscience and might be advised to examine the extensive literature that is available in the subject, particularly the Bulletin of the Atomic Scientists.

One way of resolving this problem is to devote a definite portion of each class period (say, ten minutes) to a "freewheeling" discussion of any topic related in some way to science. In this way students can talk out their concerns and opinions on a variety of subjects without unduly sacrificing the time available for the course content. Another, of course, is to permit the use of such peripheral topics for term papers and reports, in which the student is evaluated not on how well he conforms to established scientific thought but on how well he defends whatever position he chooses to espouse.

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A PATH TO RELEVANT TEACHING

by Garrett Hardin *

If I see correctly, we are at the beginning of a monumental struggle for the control of the biology curriculum, and more particularly for the control of general education courses in biology. Two visions contend for the orientation of these courses: molecular biology and ecology. Molecular biology aims at analysis on the finest scale; its goal is to explain the functions of an organism in terms of the architecture of its molecules. Ecology, by contrast, employs a global approach: it attempts to explain the interactions of organisms with each other and with the environment, to uncoverthe significance of each species in the life of others.

Within ecology there is a rapidly developing subdivision called "human ecology." Those who identify themselves as human ecologists have a temperamental liking for Alexander Pope's aphorism, "Man is the measure of all things." This statement should not be thought of as a theory, a hypothesis, or even a convention; it merely expresses the attitude of human ecologists who seek to discover the human significance of the living world.

At the moment molecular biology is on top. In the late 1950's hundreds of college and high school biology teachers joined together under the aegis of the Biological Sciences Curriculum Study (BSCS) to modernize the high school biology courses. During the several years that it took to write the three texts and the many auxiliary books and pamphlets that came out of BSCS in Boulder, Colorado, the molecular code of heredity was deciphered by researchers elsewhere. Under these circumstances it is completely understandable that the topic of molecular biology should have come to occupy the place of honor in the BSCS texts. During the 1960's universities all across the country reorganized their

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biology departments in such a way as to emphasize molecular biology. This also is understandable.

If we regard all the studies that took place before 1953 as part of the embryology of the subject we can say that Watson and Crick's paper marked the birth of molecular biology. That means the field is now less than twenty years old. A historian of science might suppose that the study is still in the first flush of its youth. This may not be the case. So great is the acceleration of intellectual progress in our time that already molecular biology shows signs of aging, if not senility.

Evidence for this shocking statement is found in the title (and contents) of an evaluation article by one of its leading research practitioners, Gunther S. Stent: That Was the Molecular Biology That Was. Stent, a student of the physicist-turned-biologist, Max Delbruck of the California Institute of Technology, entered the field early and was "in on the kill." He found it tremendously exciting; and yet by 1967 he was speaking of molecular biology in the past tense. As far as he was concerned, the party was over. It was time to move to other fields, where the grass was greener. Stent's memoirs excited a great deal of interest, and much comment--but no one seriously challenged his basic conclusion that the Golden Age of molecular biology was over.

Those who plan the future educational offerings of university departments should remember the experience of the Ford Motor Company. In the 1950's Ford brought out a new car in themiddle price range, which it named the "Edsel." It was a tremendous flop. The company lost some 50 million dollars. There were several reasons for this debacle, but the most important seems to have been that this car was brought out at the wrong time. By the time the first model finally came off the assembly line independent marketing studies had shown that the demand for medium price cars was going down. The Edsel was out of phase with historical trends.

It begins to look as though the great emphasis on molecular biology in biology curriculums is also out of phase with historical realities. Departments, caught in the mesh of committee decisions, typically take five years to revamp their courses. By the time molecular biology was introduced into the curriculums the cry of relevance was in the air. Molecular biology is marvelously exciting and very important at the most fundamental level--but is it relevant?

That is, it is relevant to the most pressing concerns of the average student,--who is no longer a passive recipient of knowledge?

Many have doubted its relevance. Some have pointed out that when the traditional courses which emphasized anatomy and taxonomy were displaced by molecular biology, the reform often meant merely that the necessity of memorizing anatomical terms and species names was replaced by the necessity of memorizing the Krebs cycle and the genetic codons. The gain in relevance is not obvious to people standing outside the field of research; that is, to 90 percent of the people who take biology courses.

Some of the promised fruits of molecular biology, for example, the cure for cancer and the molecular control of heredity, are (it is true) quite exciting to John Q. Citizen. If the promises are made good he will be delighted to accept the results. But in the meantime he has little interest in the technical details. Teachers who are most sensitive to the interests of the nonprofessional student are increasingly looking to the other end of the biological spectrum for guidance in the teaching of their general biology courses; that is, to the ecological end.

The problems and the general orientation of ecology make immediate sense to the average citizen. Warren Weaver has defined biology as "the science of organized complexity." It is apparent to everyone that the most important problems facing us in the future are tied up with the organization of this complexity of species and processes. Population, competition, aggression, pollution, informational systems, and the control of crowd diseases and informational overload--all these are easily recognized as the recalcitrant problems of our time. They are all part of the realm of ecology.

The teacher of college courses in general biology faces a number of serious tactical problems. He must first accept the awkward fact that his personal field of research may not be what the student wants most to hear about. In the past such a basic fact was largely ignored by many teachers who unthinkingly expected their students to be enthusiastic over the teacher's particular research. Whether students in the future will or will not so adjust themselves to the teachers' desires, it is all too obvious that they do not do so now. The risk of a successful student revolt is all too imminent. For this practical reason, if for no other, it behooves the teacher to ask himself: "What is relevant?"

that is what is relevant to the interest of the student who is keenly concerned with the world's problems.

Ecology is relevant. It is also exciting and rewarding to teach. It is also somewhat frightening. Paul B. Sears has called ecology "the subversive science," a label taken by Paul Shepard and Daniel McKinley for the title of a collection of reprints in ecology. Anyone who sets out to discuss the human implications of ecology soon discovers that the imputation is correct.

Consider for example the matter of population. Perhaps the most important single conclusion of population theory is that the growth of human populations must soon be brought to zero (if not below zero for a while), and must never again rise significantly above zero. This simple and unavoidable conclusion strikes at the very basis of the particular type of economic society in which we live. Every arrangement, every maneuver in our economic system presupposes the normality of perpetual growth. Whether the system can survive the necessary adjustment to a zero-growth rate is an open question, and one which the biologist cheerfully leaves to the economists to wrestle with. That we need to adopt a zero-growth rate is only one among many of the subversive conclusions of the human ecologist. Anyone who teaches a general biology course along ecological lines must expect to find himself pretty continuously on the firing line. He must learn how to survive under attack.

Such we might say, is the external problem of the biology teacher. His internal problems are no less serious, though somewhat more subtle. Why does one teach anyway? Why should one teach? What does one hope to get out of teaching? There is no reason to think that these questions have definitive answers, but a number of partial answers can be perceived.

One of the primary reasons that anybody teaches is in order to learn. That one does learn by teaching is the universal testimony of all teachers. It is quite possible that one of the dimly felt motivations of every teacher is a desire to learn a subject more thoroughly, which he can do by trying to teach it to someone else. As Jerold Zacharias has said, "if I cannot explain it to you, then I do not understand it myself"--so, let me try to explain it to you.

In the process of trying to explain the semi-known, a teacher may discover that that which is unclear to him is, in fact, unclear to everybody. As that 19th century "Renaissance man," Alexander von Humboldt, said: "It is not possible to lecture on science as science without at the same time comprehending it anew, and it would be incredible if sometimes, perhaps often, one did not come across new discoveries." The necessity of making esoteric knowledge into exoteric knowledge (whether by means of lectures or by popular writing) has led many people tonew contributions to knowledge. J.B.S. Haldane, for one, has testified that his daily newspaper columns were the source of some of his most important ideas. Publishable discoveries are an important "fringe benefit" of taking teaching seriously.

Some teachers (perhaps only a minority) are interested in the processes of teaching and learning themselves. For those with teaching as a major interest, the classroom is a laboratory and the students are the instruments. It is a most striking fact that the mostimperfect instruments are the most valuable. John Holt, a superb teacher of small children, has said that "Everything I learn about teaching I learn from the bad students."

I can bear witness to this truth. The most rewarding class I ever taught was one which I assembled by letting my colleagues know that I was offering a special section to which I would admit only students who hated science. I got them. It was the most stimulating class I ever had. Their aggressive honesty made me see more deeply into my science than I ever had before.

Some teach because they are interested in students. I am sure that the great mass of the taxpayers assume that this is the primary interest of the real teachers, and the best interest. Possibly it is; but there are reasons for seriously questioning whether an all-compelling interest in students is desirable. The psychiatrist Leslie H. Farber has broached the issue in the following terms: "Despite the modern tendency to regard all teaching relationships as primarily interpersonal in character, it is obvious that a teacher's primary dedication must be not to his students but to his subject matter. Were this not so teaching would consist only of those romantic relations, based on vanity or power, which the psychotherapist has learned to call 'transference' situations."

Once we put the act of teaching into a psychiatric framework, light is cast upon the teacher-student relationship by insights gained in the analyst-patient relationship. Karl Menninger, for example, has said: "The idea that a neurotic is suffering from a sort of ignorance, and that if one removes the ignorance by telling him facts...he must recover, is an idea that has long been superseded, and one derived from superficial appearances. The pathological factor is not his ignorance in itself, butthe root of this ignorance in his inner resistances; it was they that first called this ignorance into being, and they still maintain it now."

There can be little doubt that inner resistances are at the bottom of the most non-learning--far more often than is mere stupidity. Lawrence S. Kubie has pointed to the relevance of the phenomenon of the "idiot-savant." How does it come about that a person of extremely limited mentality can show the most fantastic ability to memorize or learn certain sorts of material? Kubie has said that this is because an idiot-savant, like a person under hypnosis, is "so nearly free of conflict as to be able to record preconsciously... and thus is able to produce extraordinary feats of memory, of lightning calculation, etc. Occasionally one encounters a man or child whose preconscious learning processes, through some happy accident, operate freely. He learns effortlessly. To the consternation and anger of his classmates he wins highest grades in a heavy schedule without studying."

It is really very disturbing when you stop to think of it (if you are genuinely interested in students themselves) to realize that the vast majority of our students--certainly well over 99 percent of them--never achieve more than a small fraction of their potential, where potential is thought of as some sort of naked I.Q. The study of people under hypnosis and of idiot-savants gives us some idea of what education might be if we were dealing with students free of disabling conflicts. Perceiving the vast gap between potentiality and reality we cannot but agree with the philosopher Alfred North Whitehead, who said: "When one considers in its length and in its breadth the importance of this question of the education of a nation's young, the broken lives, the defeated hopes, the national failures, which result from the frivolous inertia with which it is treated, it is difficult to restrain within oneself a savage rage."

Yet what are we do to? Whatever we do, it is undoubtedly essential that we keep the deepest problems to ourselves, that we not burden the student with them. Many true things are better not said. Vis-a-vis the student we had better act as if the whole truth were as stated by Farber; namely that "a teacher's primary dedication must be not to his students but to his subject matter." The reason for adopting this working procedure is deep grounded in biology. Anyone who h has worked with the higher apes has learned the inadvisibility of insistently facing an ape directly, of insisting on eye-to-eye contact. Resentment, fear, and aggression are the ape's responses to the experimenter's insistence.

Noli me tangere --"touch me not"--is the classic Latin verbalization of this universal resentment of an intrusion into one's private self. The biological basis of the feeling is deeper than words. To work productively with a learning animal you must focus his attention (and yours) outside the privacy of his deep and important needs, fastening upon the objects of the world. The human animal is not significantly different from any other in this regard. In the beginning, and most of the time thereafter, our greatest successes in teaching are achieved by indirection, by avoiding too personal a contact. Most of what we know of the students' needs we must keep to ourselves.

The teacher who tries to achieve too personal a contact will be spotted by the sensitive student as one who should be suspected of desires based on vanity or power. To seek "transference," even unconsciously, is to arouse defenses on the part of the student.

One more thing must be said, though it must never be said to the student. The ideal relationship, the relationship in which the student enjoys the greatest freedom from conflict, is a relationship which follows as a consequence of an act of affiliation by the student. "Affiliation" comes from the Latin word filius, son. To achieve his maximum potential the student must, for a time, become as a son to one whose competence justifies the voluntary abandonment of egoistic resistances. It must be a voluntary affiliation, one not imposed by authority or even achieved by pedagogic seduction. The affiliation mustbe a consequence of the student's seeing the teacher at his very best. Whitehead has stated the issue most succinctly: "It should be the chief aim of a university professor to exhibit himself in his own true character--that is, as an ignorant man thinking...." The student who affiliates himself to such a man has no fear of discovering feet of clay--nor of uncovering evidence of intellectual seduction, for there is none. To such a one the student grants authority--and thus becomes free to learn.

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THE EARTH SCIENCES

by Sheldon Judson*

The study of the earth as a regular discipline has been going on since the late 19th century, but the term "Earth sciences" has become generally current only within the last few years. It embraces many sub-disciplines. The National Roster of Scientific and Technical Personnel lists earth scientists as those who practice geology, paleontology, geophysics, hydrology, geochemistry, oceanography, geodesy, and geomorphology. It also includes a miscellaneous category under the term "other." About 60 percent of those listed by the register consider themselves geologists.

The teacher at the introductory level will find himself dealing with the subject matter of all the disciplines listed above and of some others such as meteorology and climatology, soil science, cartography, mining engineering, conservation, and the emerging subject now ineptly called "astrogeology".

Obviously no scientist is going to boast of expertise in all of these subjects, and no teacher will be called upon to offer instruction in depth in all of them. Every teacher will, however, certainly find it worthwhile (even necessary) to have some understanding of certain aspects of most of these fields. In addition to this intellectual smorgasbord the student of the earth, whatever his sub-discipline, will find it necessary to digest certain amounts of biological science, physics, chemistry, and mathematics.

These comments serve to emphasize that the study of the earth cuts across many fields of knowledge. It is truly an inter-disciplinary undertaking. There are considerations, however, which give coherence to the earth sciences and which save them from becoming a disjointed, undirected collection of activities.

A FRAMEWORK FOR THE EARTH SCIENCES

Most obviously the focus of the study--the earth--provides a direction and a concentration for teachers' interests and knowledge. There is, however, a general framework within which the earth sciences function. It will pay teachers to examine it briefly.

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A science is defined as an organized body of knowledge, and the earth sciences are defined as an organized body of knowledge about the earth. If one examines the nature of the earth sciences more closely, however, he can see that the subject can be viewed as composed of three separate parts, namely: (1) Systematics; (2) geography; and (3) time (history). These are shown in figure 1 as a first approximation of a model for the structure of the earth sciences. In this model the examples of systematics have been taken from geology, but others such as meteorology, pedology, or hydrology would be equally useful. (The discussion of the structure of the earth sciences is adapted from a longer treatment by Judson in the Transactions of the New York Academy of Sciences Ser. II, vol. 20, No. 4 pp. 305-315, 1958.)

Systematics

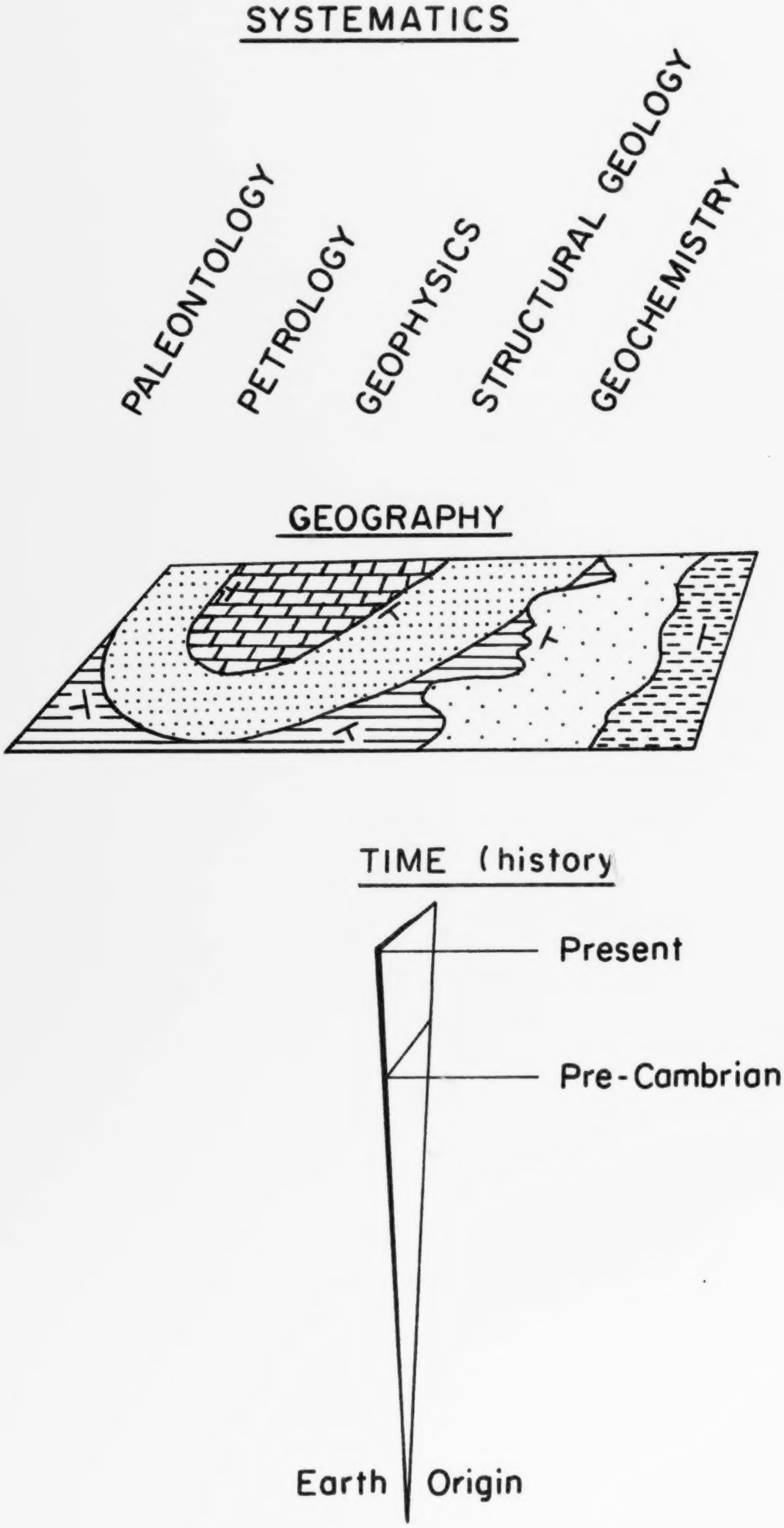
Systematics refer to classification. In the earth sciences there are many systematics. For instance, scientists classify minerals on the basis of their crystal systems, their chemical compositions, the arrangement of their atoms, or their physical characteristics such as hardness, cleavage, and streak. The pigeonholes of paleontology are as familiar and as necessary as those of mineralogy. Petrology, geophysics, geochemistry, and structural geology, as examples, can all be considered as systematics of the earth sciences. One can view these and many others as ways of studying and ordering certain data concerning the earth. Outside of the earth sciences, one can classify chemistry, physics, and much biology as systematic sciences. Each of these three sciences contributes to the effectiveness of one or more of the systematics that are used in earth science.

Geography

The relation of things in space is of vital concern to the earth scientists. The geographer may map the distribution of world climates and perhaps determine the relations of climatic differences to soil types, industries, or population densities. This activity, scientists would certainly agree, is of concern to the geographer. But the role of geography in the general field of earth sciences is broader. For instance, a geologic map shows, among other things, the geographic distribution of rocks at the earth's surface and also suggests the arrangement of these rocks beneath the

FIGURE I

THE MAJOR ELEMENTS IN THE EARTH SCIENCES CONSIDERED AS SYSTEMATICS, GEOGRAPHY AND TIME (HISTORY).
Adapted from Judson 1958.


SYSTEMATICS
PALEONTOLOGY
PETROLOGY
GEOPHYSICS
STRUCTURAL GEOLOGY
GEOCHEMISTRY
GEOGRAPHY
TIME (history
Present
Pre-Cambrian
Earth Origin

earth's surface. Paleogeographic and paleogeologic maps depict spatial relationships and, as such, are geographic.

Time (history)

The earth sciences are history. Perhaps more than any other single characteristics, the time factor distinguishes earth science from the other sciences. The idea of time as an integral part of earth study is not new. The Scotsman, James Hutton, often cited as the father of modern earth sciences, said in 1795 "the natural operations of this globe, by which the size and shape of our land are changed, are so slow as to be altogether imperceptible to men who are employed in pursuing various occupations of life and literature." The late Adolf Knopf wrote in 1949 that "the single greatest contribution" of the earth sciences" to modern civilized thought ...is the realization of the immense length of time...recorded in the history of the earth."

It is time that gives perspective to the systematic and geographic aspects of the earth sciences. It is time that distinguishes the earth sciences from sciences such as chemistry and physics which rely primarily upon the classification of things and objects. Probably the science that most closely resembles the earth sciences is astronomy, which deals not only with systematics, but also with space (geography) and with time.

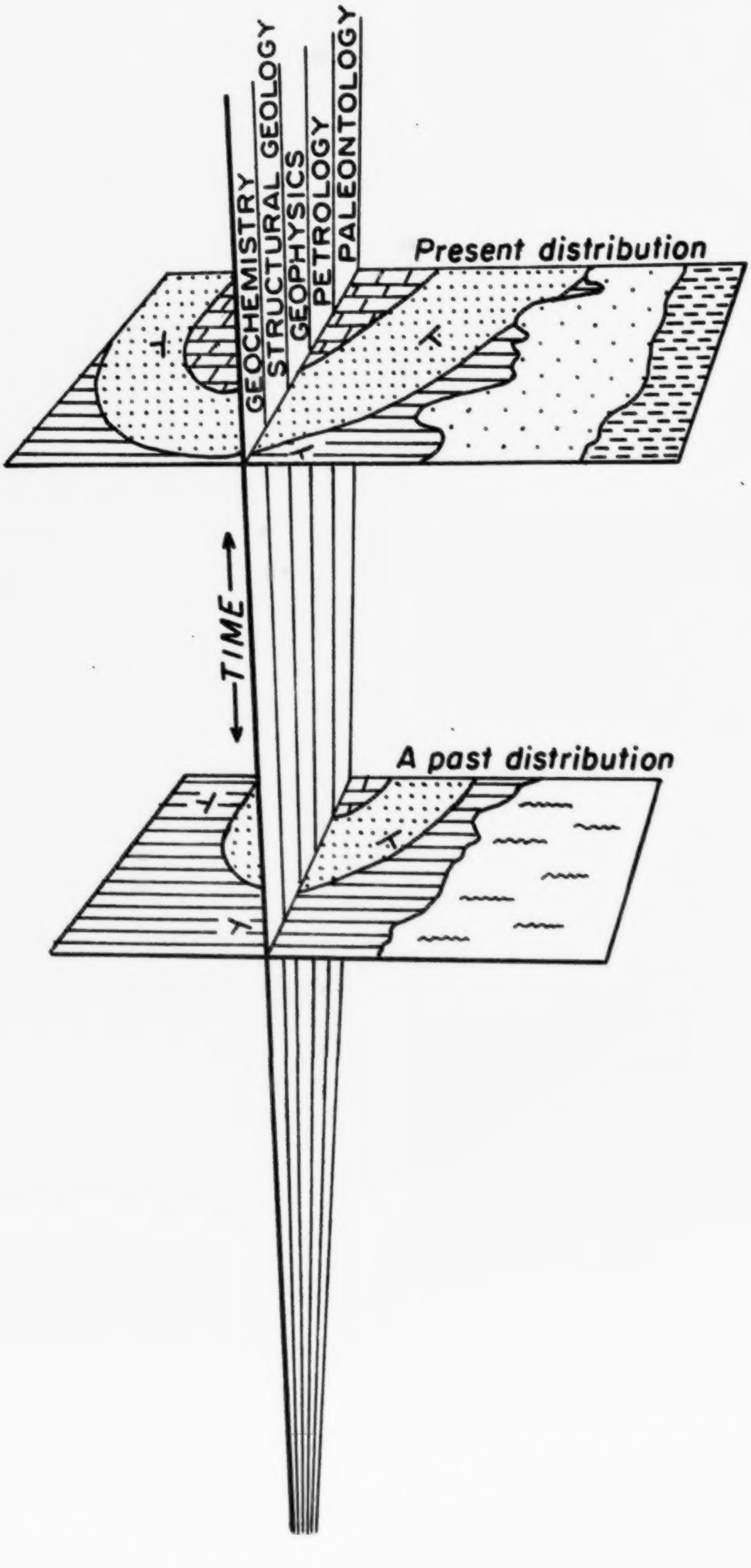
These three elements--systematics, geography, and time--can be combined in a single diagram as shown in figure 2. In the example given, the geologic maps represent spatial relationships (geography) of the present and of some past time. Paleontology and the other systematics can be considered independently of these maps, or they can be used in their construction. In another context the systematics are arranged on a vertical plane (time) and may be treated historically. In this sense paleontology ceases to be a study in taxonomy alone and becomes the study of organic evolution. Many other examples, using different systematics and different geographies, can be arranged on a time axis.

The analysis of the structure of the earth sciences is obviously not a basis for the construction of teaching outlines. But it may be useful for a teacher to recall occasionally the relationships the model depicts, particularly while he is dealing extensively with some specific aspect of the earth sciences.

Some observations flow from this short survey of the wide variety of disciplines that are included within the earth

FIGURE II

SYSTEMATICS, GEOGRAPHY AND TIME FORM A FRAMEWORK FOR THE EARTH SCIENCES. Adapted from Judson 1958.


GEOCHEMISTRY
STRUCTURAL GEOLOGY
GEOPHYSICS
PETROLOGY
PALEONTOLOGY
Present distribution
TIME
A past distribution

sciences and from the analysis of the framework within which these disciplines are applied to a study of the earth.

It is apparent that the organization of subject matter, at least for an introductory course, can have a very wide range. The plan that a teacher follows in any one course will obviously be conditioned by the demands of his colleagues; by his own talents and interests; by the library, laboratory, and field facilities; and by student interest, abilities, and needs.

It is also clear, as is noted earlier, that no one teacher is going to be qualified in all the sub-disciplines of the field. And even if he were, it would be impossible for him to pass along an organized body of knowledge. Despite this fact, the earth science teacher will wish to keep abreast of the changes in established areas of the field and understand to some extent what new areas are opening up. This can only mean that he like other scientists is involved in continuing his education, either formally through institutes, short courses, and conferences or informally through reading, listening, and talking.

THE CLIENTELE

Shamos, in an earlier chapter, points out that college students of science divide naturally into those taking science because of their field of specialization (a science) and those taking introductory science courses to satisfy distribution requirements. He points out that the latter group is by far the larger. The earth sciences provide no exception to Shamos' generalization.

Of the students taking their first college course in earth sceince, for whatever reason, few will have very much background in the subject. It is true that an increasing number of secondary school students take some form of earth science. But few of those who have had a course, have had training of any great depth. What is important is that they have been exposed to some aspects of the subject, and the teacher of an introductory course in college will wish to make some adjustment to this fact in his own teaching. The kind of adjustment needed will be for the individual teacher to determine for it will depend not only on the student and his background but on the college instruction being offered.

The "scientists" taking earth science in college are of two types: (1) those intending to concentrate in the subject during their undergraduate years and (2) those taking the subject because it is relevant to another science in which they intend to concentrate in college. A large percentage of each of these groups may well go on to become professionals and to make their careers in the earth sciences or some other science. For those who become earth scientists the introductory courses will serve to spark their interest in a career in the subject or confirm an already expressed interest in doing so.

Students who are bound for some science other than the earth sciences will make widely varying demands upon the subject. For some a fairly standard introductory course may be all they wish and need. Others may need special types of courses such as "geology for engineers," or mineralogy, or meteorology, to name but a few. Important as the others may be, it is the large group of non-scientists who take one or two courses in the earth sciences that will command the most attention at the "first course" level. Although the size of the non-science group is not exactly known some figures are available. The American Geological Institute reported that approximately 124,000 non-major students were taking courses in departments of geological science in 346 American colleges and universities in the academic year 1967-68. Of the total, nearly 115,000 were enrolled in geology; about 3,300 in oceanography; 4,700 in "teaching"; 800, in engineering and 500 in geophysics. An additional 31,000 were taking courses in these subjects in 181 four-year colleges which gave no degree in an earth science. If the numbers in 4-year schools not reporting and in 2-year institutions are added, the total number of non-major students taking a "geoscience" course is estimated to be about 200,000. When the estimated number of students taking courses in physical geography, in meteorology-climatology, and in soils is added, a very crude estimate of all non-major students in the earth sciences at the college level would be 400,000 or more.

OBSERVATIONS ON INSTRUCTION

Probably one thing that almost all of these "first-course" students have in common is that they are enrolled in the earth science courses to satisfy a science distribution requirement. As such they constitute a captive audience. This does not mean that all in the audience dislike being captives. Most, probably, are either pleased to be in the audience or at least neutral. Few are apt to be hostile. Be that as it may, what can one say about designing effective instruction for this audience? One comes back again to the fact that there is a wide range of possibilities.

It is probably realistic to assume that a great deal of the instruction for the non-major will center on the traditional type of introductory courses. They will have some sort of mix of lecture, class laboratory, and field work and will rely on standard texts. But here are some observations on other types of courses.

Oceanography has rapidly become a very intriguing subject to students. The student seems to find in it the mystery and adventure of the unknown. The experience in my own college indicates that an introductory oceanography course enrolls as many students as the departmental introductory course in geology. The course does meet science distribution requirements, but only if the student elects to take the optional laboratory, something most students do not do. So they seem to be taking the course because of an intrinsic interest in the subject matter and not to meet a science distribution requirement.

The interest in space exploration has created some interest in introductory courses in a science generally called "astrogeology". Some, in fact, exist. Apparently they are considerably less popular and successful than oceanography is. This may be in part because teachers have difficulty in assemblying suitable material; in part because an adequate body of knowledge is lacking, and in part because students may need considerable sophistication in mathematics and physics to participate in astrogeology. Despite the problems this course is having, the study of other bodies in our solar system offers great potential for an introductory course or for a large portion of one.

More easily presented and perhaps even more relevant to the times than astrogeology is a course in a consideration of man's environment and the interaction between man and his environment. Unlike "astrogeology" such a course offers the possibility of study at several levels and a large body of information. Furthermore, the subject matter cuts across many of the sciences, and the scientific data included have social, economic, and historical implications.

In the same general field as the "environment" course is one which deals with the economic resources of the earth. Here one might consider the geography of mineral wealth, its distribution, its economics and its exploitation.

The history of science is a subject which continues to have the support of many academicians. Some attempts have been made to interweave the history of thought in the earth sciences with the subject matter of a standard introductory course, or even to base a course almost completely on historical material. I know of no particularly successful attempts in this area. I can attest to at least one failure, my own. My own experience, for what it is worth, suggests that seniors, and first year graduate students,particularly if they are majors in theearth sciences or in the history of science, respond more positively to the "history of science" approach than do the introductory students.

What can one say about instruction designed for those concentrating in the earth sciences as undergraduates? Because many of these students will be choosing a career and graduate work in the area the answer must deal with a preprofessional program. A quick and effective way to check the professional relevance of the content of the undergraduate program is to judge it by the suggested requirements for admission to the various graduate departments in the disciplines concerned.

In addition considerable room for innovation exists at the preprofessional level. Not new, but worthwhile, is the use of independent work in the curriculum. One often thinks of independent work as available only on an "honors" basis. Experience suggests, however, the independent work can be successfully carried out by most non-honors students. In fact there is a good reason for believing that less promising students benefit more from the experience than do the better qualified students. To accommodate the less talented, less highly motivated, or less well-trained student, teachers need only change their expectations and demands of him. But one shouldn't be surprised if the less able student actually produces a much better product than either he or his teachers would have predicted possible. As a variant of the independent work approach one should not forget that seminars, reading courses, problem oriented courses can be used with profit under various circumstances.

In considering independent work, one must remember that it is a very effective technique for those who are non-science majors. Generally even the first year, non-scientist will respond well. The chief problem, obviously, is to find the time and the manpower to conduct this type of instruction at the introductory level. Experience indicates that when this can be done independent work of whatever kind is rewarding to both the student and the instructor. It should be instituted whenever and wherever possible.

Some institutions have experimented, with varying degrees of success, with student-initiated courses and seminars. These have much merit in principle, not the least of which is the transfer of much responsibility to the student. The successful attempts seem to be those in which students and the enlisted faculty supporting them contribute careful planning to the structure and mechanics of the undertaking.

The place of field work in earth science instruction should be considered by the teacher. Many experts in the field are persuaded that the more field work, formal and informal, that a student participates in the stronger will be the curriculum. This applies at all levels from the introductory first-year course to senior independent work. Whatever devices can be used to get the students into the field are almost always worth the effort. Field work not only has its obvious formal pedagogic uses but is also very suitable for independent work.

SOME INFORMATIONAL SOURCES

No attempt is made to discuss audiovisual teaching aids here. A brief treatment will be found in the chapters by Professor Shamos and Professor Lippincott. Nor is any attempt made to list either the standard periodical and occasional publications or the leading texts and other books. The following list of organizations, however, may be useful. Additional organizations of importance to the teacher will be found at the end of the chapter by Professor Shamos.

American Geographical Society
Broadway at 156th Street
New York, New York 10032
(A society of professional geographers, teachers of geography, and others interested in geography. Publications, large library, including photographs and maps.)

American Geological Institute
2201 M Street N. W.
Washington, D. C. 20037
(A federation of 16 societies of geology and geophysics. Numerous useful publications and programs.)

American Meteorological Society
45 Beacon Street
Boston, Massachusetts 02118
(A society of professional meteorologists and non-professional students. Welcomes inquiries.)

Earth Sciences Curriculum Project
P. O. Box 59
Boulder, Colorado 80302
(For information pertinent to secondary school programs and teacher training programs.)

National Association of Geology Teachers
Department of Geology
City College of New York
New York, New York 10031
(An association of secondary, college, and university teachers of geology and other earth sciences. About a dozen active regional sections. A useful organization to the teacher.)

National Council for Geographic Education
Illinois State University
Normal, Illinois 61716
(An association of secondary, college, and university teachers of geographic education and a useful organization to the teacher.)

Secondary School Science Project
Graduate School of Education
Rutgers University
New Brunswick, New Jersey
(For information pertinent to secondary school programs and teacher training programs.)

U. S. Geological Survey
General Services Administration Building
F Street between 18th and 19th Streets, N. W.
Washington, D. C. 20242
(Provides publications, maps, photographs, and information of various kinds.)

Additional sources of information in the earth sciences can be found in "Geology and Earth Sciences Sourcebook" by Robert L. Heller, Editor, Holt, Rinehart and Winston, Inc.: New York, 496 pp. 1962.

There are many additional professional organizations in the earth sciences. Two useful directories are "Scientific and Technical Societies of the United States and Canada," 1961, publication 900, National Academy of Science-National Research Company, Detroit, Michigan, two volumes, 5th edition, 1968. This last reference is brought up-to-date quarterly in a loose-leaf publication.

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THE TEACHING OF COLLEGE CHEMISTRY

by W. T. Lippincott*

PERSPECTIVES FOR CHEMISTRY TEACHERS (1)

Since requisite understanding of the sphere of knowledge commonly designated as chemistry is generally regarded as a cultural if not a professional imperative in our time, and because so few have acquired such understanding without formal education in the subject, the chemist who accepts a position that includes teaching duties also must accept the major challenge of seeing to it that the acquisition of such understanding comes clearly within reach of his students. The basic problem here is incredibly difficult --the total amount of chemical information doubles every 7½ years; modern technology converts new knowledge to new products almost instantaneously, exponentially the citizen's need to comprehend both the fact and its implications; the teacher must provide the basis for broad and deep understanding of the subject matter, for the development of specific skills essential for the specialist, for appreciation of the method and spirit of the scientific effort, for the stimulation of thought, creativity, and wisdom.

Experience suggests that to be effective in the classroom the instructor needs a thoroughly competent grasp of the subject matter, more than a little skill in communicating difficult ideas, some knowledge of how students learn and how to measure this, a reasonable set of educational objectives, and a humanistic empathy that encourages honest dialog between teacher and students. Remarkably perhaps, the college teacher must respond in awareness if not in harmony with all of this, meanwhile developing and sustaining an active and productive research program in his specialty.

It is not surprising that many faculty members place priorities on the various facets of their effort, with the result that certain of these receive more attention than others. For the beginning faculty member there is perhaps no judgment more sensitive than that of striking that critical balance between the effort to be given to research and that to formal teaching. While this balance will depend in considerable measure on the educational objectives of the institution, nearly all beginning faculty members want to excel in research and to teach well. Nearly all seek a balance that will insure rapid but healthy professional development in both areas, and one that will enable them to meet with prudence the day-by-day obligations to students, the on-going institutional responsibilities, and the deep-rooted commitment to scholarly productivity. For most this means very long days and virtually nonexistent week-ends. And because research is the most demanding of all mistresses, many faculty members sooner or later find themselves confronted with the hard choice of neglecting the teaching or abandoning the research. The morality of the moment would seem to place greater value on the former than on the latter. Hopefully, however, the needs for quality in both teaching and research are recognized by all who care.

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The great teachers of chemistry, as identified by their former students, themselves both chemists and nonchemists, have served at schools of all descriptions large, small, accredited, unaccredited, gratuate-oriented, undergraduate-oriented. These teachers include some top researchers and some who did no significant research after leaving graduate school. The criteria for their effectiveness appear to include, in addition to knowledge of the subject, sincere interest in the course being taught and in the students present. For theless successful instructors, the cardinal sin appears to be not in teaching something unfashionable but in not knowing the modern view; not in expecting too much of the students but in not sensing their needs.

PEDAGOGY IN COLLEGE CHEMISTRY (2)

Formal chemistry instruction extends from the broadly representative, principles-oriented compendium designed as an introductory overview often for non-science majors, through the highly specialized, precision-inculcating courses that dominate the curriculum for majors, to the open-ended, free-wheeling discussions characteristic of the research seminar. The introductory courses, and to a lesser extent, most other undergraduate chemistry courses, contain sizable numbers of nonmajors and therefore must serve the educational needs of many who will not follow chemistry as a career. Most of the same courses also must enable those who aspire to be professional chemists to gain the comprehensive knowledge and develop the initiative and judgment essential to success.

Exclusive of the seminar the method of teaching most often used in college chemistry is the familiar lecture-recitation-laboratory pattern. This usually is supplemented by a textbook, laboratory manual, and other reading materials including the original literature. The primary goal of most chemistry courses is to familiarize the student with a limited area of chemical knowledge, to require that he understand this thoroughly and able to use it facilely, and to demonstrate the method by which this knowledge was obtained and verified. Given this goal, the lecture is a particularly effective focal point for chemistry instruction, for there the teacher can illustrate his special skills in handling the subject matter--skills that many may find difficult to learn from written material. For example, the lecturer can show how various pieces of knowledge can be synthesized to produce a desired or perhaps unexpected result, he can utilize the techniques of induction or deduction as they might be needed in a given situation. He also can point out the implications of the knowledge being considered, separating the more important from the less important in a way that is designed to help develop and sharpen the student's judgment and discriminatory talents.

Although the teacher might be able to illustrate this same skill, with perhaps even greater versatility in a small-group discussion session, the more formal lecture may be the better method for much chemistry instruction because it provides an additional measure of intellectual discipline to accompany the attempt by the teacher to demonstrate and develop intellectual freedom. Some teachers who have tried the small-group discussion technique have been heartened by student response, but frustrated by their own inability to stimulate student thinking on more than one small topic during a class period. They believe that where the lecture may impose too much discipline on student thought, the free discussion provides too much unproductive mental activity. For efficacy most chemistry instruction requires a rich blend of freedom and discipline which an experienced lecturer with cogent organization of the material, skillful questioning of students, appropriate lecture demonstrations, and other visual aids can initiate.

Despite this, experienced lecturers recognize that students retain very little hard knowledge from the lecture itself. What is retained are some ways of thinking and some attitudes toward study. A technique that has proved especially effective is to use the lecture in part as a means of convincing the student that the material under study is important, that he can master it with a reasonable but usually persistent effort, and that the mastery of it will enrich his intellectual proficiency. With this kind of motivation high, but realistic standards of student performance can be, indeed must be, expected and maintained.

In large undergraduate courses the recitation is used chiefly to provide each student with the opportunity to engage in a dialog with an instructor. Here the instructors, in classes of from 20 to 25 students, accept questions from those who raise them and direct questions to those who do not. In addition to aiding the students in articulating their difficulties and their ideas, recitations also give instructors an indication of the extent of student learning.

The laboratory has as its major goal practice in the method of science but includes most often practice in the use of important manual or instrumental devices for obtaining products or data. For the most part this kind of training is essential for sciencemajors and for students who plan careers as technicians; however, its value for the non-science student has been questioned. As a consequence laboratory programs have been designed, mostly for non-science students, that emphasize laboratory based problem solving. Often such programs involve planning the attack on the problem, extensive designing of experiments, collecting and interpreting data, testing hypotheses, and arriving at generalizations. However, because of the complexity of chemistry, the depth of its body of knowledge, and the sophistication of its experimental development, the design of significant or even highly relevant programs of this type is progressing slowly.

These difficulties are the basis for the major current problems of present-day laboratory instruction in nearly all chemistry courses which is how to provide in the time and available facilities both training in the use of hardware and experience in attacking realistic chemical problems to a degree that even approaches in sophistication the kind of experimental competence required of creative laboratory workers today. For beginning teachers especially this is an area ripe for innovation.

EXAMPLES OF INNOVATION (3)

Some innovation has begun, and not only in the laboratory. Much but not all of it is centered on the use of audiovisual techniques. Old and often well-founded suspicions of these techniques are giving way to the realization that certain aspects of chemistry instruction might better be handled with the aid of media such as short, to the point, films for individual student viewing, television tapes which can bring into the classroom important complex instruments essential in chemical research but heretofore unseen by all but a few students, and computer-assisted instruction programs which make possible a student-teacher dialog by means of a computer.

As an illustration of the kinds of innovation now being attempted in chemistry programs, the following series of one-sentence descriptions may be useful.

The advent of relatively inexpensive ($1,500--$5,000), portable, instructor-operated television tape-recording and play-back systems has made it possible for instructors to prepare their own tapes only a short time before class, if necessary, and to show their students items that might be essential to student understanding, but very difficult to present advantageously otherwise; such items might include dangerous experiments, inaccessible instruments, and intricate laboratory techniques.

Computer-animated films on topics such as molecular vibrations, chemical bonding, behavior of gases, reactions in progress are generated with the aid of a computer which displays the models on a screen and moves them in accordance with the known equations of motion.

Similar in many ways to programed instruction, computer-assisted instruction enables an instructor to program the computer so that it can enter into a Socratic dialog with a student or students; in the dialog the student sits at a computer terminal and, in most cases, types a message to the computer; the computer responds with a typed statement to which the student is expected to reply.

Overhead projectors, already widely used for enlarging demonstrations, are being designed so that their images can be projected on a series of screens across the front of the room, thereby eliminating the need for chalk boards.

Digital read-out devices like small basketball scoreboards are being installed in science lecture halls so that measurements of temperature, pressure, pH, electromotive force, and the like can be made during a lecture experiment and displayed instantaneously; students can take down the data and use it in discovering relationships.

A 16mm movie projector has been modified so that the instructor, holding a push-button control in his hand, can direct the projector to show one or several short film sequences, repeating a sequence if desirable; this makes it possible for an instructor to insert very short, pertinent film passages into lectures just when they can have the greatest impact.

Response systems give each student a five-position switch at his seat with which he may respond in any of several ways to the instructor's queries; student responses are collected on a read-out at the instructor's desk.

There is being developed a computer terminal which can be placed at the front of the classroom and arranged so that the responses from the computer can be displayed on a large screen; the instructor will be able to call for any of more than two thousand displays from the computer and to receive his request in seconds.

Student study carrels are being used in ever widening applications.

Dial-access systems which permit a student in his dormitory or in a learning center to dial a lesson and have it come to him by means of audio or video receivers are in operation at several large schools.

EVALUATION, TESTING, GRADING

Evaluation, testing, and grading--always arduous--offer some special challenges for the chemistry teacher. How to evaluate laboratory performance; how to test for knowledge, skills, abilities, and aptitudes and obtain an equitable measure; how to provide expression for the creative mind without penalizing the good scholar; how to stimulate flexibility in reasoning; how to be certain the test measures what it is designed to measure? What should the standards be? Each teacher has his own answers to these questions and builds his evaluative procedures accordingly. Some favor oral examinations, term papers, and other devices that emphasize freedom of student expression, but most seem to depend on written tests and quizzes where specific points can be examined, the results compared, and the students rated accordingly.

Perhaps the most common policy in undergraduate chemistry courses is to base the course grade on a sizable number of evaluations--several midterm examinations, weekly quizzes, weekly or biweekly laboratory reports, for example. In this way both the instructor and the students can keep a running evaluation of how things are going.

Many instructors feel it is especially important for a student to write out answers or to work out problems on tests --that this provides a valuable measure of his ability to respond to a given situation. In large classes where grading hundreds of papers fairly and consistently may become a problem, tests that are in part objective and in part subjective have been used extensively. Practice in writing objective examinations, perhaps with initial help from professional examiners, has convinced many teachers that objective tests can measure a good deal more than recall of facts.

Examinations in which a large number of grades fall into a narrow range of scores suggest that the test does not discriminate well. When this range lies on the high end of the scale it would appear that the better prepared students were not given an opportunity to show the extent of their preparation. When this range lies on the low end of the scale it might indicate that the test is not discriminating the students who did not prepare at all from those who prepared but evidently not in tune with the instructor's expectations. Instructors who consistently see this kind of result on their examinations might be doing a disservice to their students.

COURSE CONTENT AND CURRICULUM (4)

Chemistry teachers seldom become bored by the subject matter. Its ever-refreshing expansion and intensification are as much a challenge as they are a delight. In course and curriculum development the problem is obviously one of selection and balance. Historically the desire to provide students with a strong base of understanding led to an emphasis on fundamental principles and this in turn led to a predilection for theory. The strategy was to recognize that since the body of chemical knowledge was too vast for anyone to assimilate, reasonable competence is possible only through understanding of principles supplemented by the ability and experience to use these principles as an aid to recalling facts and a predictor of chemical behavior. The difficulty is that the theory itself has become so voluminous and intricate that often nearly all of the course time is required to develop this alone. Consequently decreasing emphasis is given to applying the theory toimportant chemical problems. A valuable contribution can be made by teachers who can find ways to restore the balance between theory and application in chemistry courses.

The undergraduate curriculum for chemistry majors, immutable for years, is currently the subject of considerable experimentation. Variations being tried extend from compressing the traditional 4-year program into 3 years through teaching physical or organic chemistry during the freshman year to completely abandoning courses in the classical areas of chemistry in favor of concept-centered topics. Nearly all of these experimental curriculums feature undergraduate research; most offer more electives in chemistry and in other sciences than the traditional curriculum provided. Very likely curriculum reform is in its infancy with the major breakthroughs of the century yet to come.

It has been argued for years that the course for non-science majors is the most important single course taught by chemistry teachers--that it provides the only palpable basis most students acquire for understanding the matter-sphere; that it adds a new dimension of reason to their attitudes toward nature and toward the technology that demonates our age; that it gives them cultivated insight into what must be one of the most successful endeavors ever attempted by the mind and spirit of man; that it serves as a vital communication link, and possibly the major center of dialog between the chemist and the citizen, between benefactor and benefited, in a situation where these roles interchange regularly. What such courses necessarily lack in rigor and depth they presumably compensate for in excitement, in relevance, and in a kind of practical wisdom. The major question is: Who among the faculty has that special breadth and depth of knowledge, that extraordinary judgment and perception, that unusual, almost instinctive, ability to reach and motivate the students so as to create a course neither too challenging nor too shallow, neither unreliable in its romanticism nor ossifying in its attention to detail?

In this question, its answer and its implications, probably rest the reasons the non-science course never has reached its potential. However, the importance of this course cannot be overemphasized, and its possibilities are almost without peer in college chemistry instruction.

There has been a lot of talk in recent months about relevancy in college instruction. At the height of all this, a maturing professor of chemistry began his first lecture to a new class of freshmen with the following:

> In this course we shall take a serious look at man's efforts to interpret the universe. We shall consider such things as how the chemical elements probably were formed, why they have the properties they exhibit, and how they form the myriad of substances that make up the material world. By the end of this course you should be able to describe with some measure of confidence many of the reactions that take place on the earth, on several planets and in the stars, even the farthest star in the farthest galaxy in the universe. And you should have some knowledge of many of the chemical processes that keep your bodies alive and healthy.

Somehow there seems to be some relevance in these words and in what they promise. This relevance and this promise are an important part of the heritage every chemistry teacher carries with him each time he stands before a class.

Suggestions for Further Reading

1. For other ideas on this topic see:

(a) Alvin M. Weinberg, "The Two Faces of Science," J. Chem. Educ., 45, 74 (1968).

(b) Eric Hutchinson, "Fashion in Science and in the Teaching of Science," J. Chem. Educ., 45, 600 (1968).

(c) Eric Hutchinson, "Science, A Component of Liberal Education," J. Chem. Educ., 44, 261 (1967).

2. For Elaboration on topics in this section see:

(a) John H. Woodburn and Ellsworth S. Obourn, Teaching in the Pursuit of Science, The MacMillan Company, New York, 1965.

(b) Handbook for Chemistry Assistants, Chemical Education Publishing Company, Easton, Pennsylvania, 1967.

(c) J. A. Young, "What Should Students do in the Laboratory?," J. Chem. Educ., 45, 798 (1968).

3. For detailed information on the hardware and software of innovation see:

(a) Modern Teaching Aids for College Chemistry, Advisory Council on College Chemistry serial publication number 18, 1966.

(b) W. R. Barnard, "Teaching Aids," J. Chem. Educ., 45, 63, 136, 206, 341, 543, 617, 681, 745 (1968).

4. For additional reading on content and curriculum see:

(a) "Symposium on Chemistry for Non-Science Majors," J. Chem. Educ., 45, 550 (1968); 46, 64, 66, 69, (1969).

(b) "Recent Trends in Undergraduate Chemistry Curricula," J. Chem. Educ., 41, 126-147 (1964).

THE BEGINNING TEACHER OF COLLEGE MATHEMATICS

by R. L. Wilder [*]

CULTURAL BACKGROUND OF THE BEGINNING TEACHER

One of the most important attributes that the new teacher of college mathematics should have acquired (in addition to the ability to handle the subject matter he is to teach) is knowledge of the general character of mathematics and its place in our culture. Some of the poorest teaching of mathematics is traceable to the instructor's treating his subject as though it had no connection with anything beyond its own confines.

This does not mean that it is sufficient for the instructor to bring in "applications" (something which may be quite difficult, since the students in the usual elementary college course have a diversity of ends in view). Rather, it means showing the relationships to those matters that form part of everyone's experiences, such as the humanities, and especially languages and philosophy. It includes, also, a general knowledge of the origins and intrinsic meanings of the topics covered. Mathematical "laws" (as the "laws of arithmetic") were not revealed to a Moses and handed down to the academic world. They are a human construction that evolved like any other aspect of human behavior; and although the rigid departmental structure of today's colleges seems to set mathematics firmly apart, the lines of separation from the other sciences and humanities are artificial.

If the new teacher has not himself been taught in such a way as to have already acquired such knowledge, it is not necessary that he take courses in history of mathematics or in philosophy of mathematics as a remedy for his deficiency. Indeed, these courses may not be taught in such a way as to provide the desired information. He may do better simply to browse among the books and articles that give explicit attention to these matters (e.g., Bell 1945; Kline 1953; Wilder 1968). Throughout most of its history, mathematics was treated as one of the "liberal arts," needing no justification in the way of what are today called "applications." It has been only in the last century or two, when pressures mounted for inclusion of many new fields in the college curriculum, that such justification was thought necessary. This is not to imply that the applications of mathematics are not worthwhile or important; they are. But they are only part of the cultural environment that has influenced and motivated mathematical evolution.

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Mathematics as a "Language"

It has become fashionable to call mathematics "the language of science." A little analysis of this conception of mathematics is revealing. Considerthe statement, "Mathematics is a language," which, while less restrictive, carries similar connotations. Since languages are usually considered part of the humanities, this would make of mathematics a humanity--for which there are other more substantial grounds than this. Mathematics has many humanistic aspects that are not recognized so well today as they were during its "liberal arts" years. There was a time, during its early evolution, when mathematics was really part of the language of ordinary discourse. Moreover, if one analyzes the manner in which English is taught (as a native language), one finds procedures quite similar to those employed in the teaching of early numerical and arithmetic facts. The parent uses such procedures intuitively, while the grade school teacher uses the methods he was taught during his professional training. But although the rules (grammatical in English, operational in arithmetic) and the problems posed may differ intrinsically, the analogy is very strong until the greater abstractions of the individual subjects are reached. In English courses, as traditionally developed, instruction becomes more literary at this stage, involving rules for writing fiction, non-fiction (especially exposition), and poetical forms, for instance. In mathematics, on the other hand, generalization (e.g., from arithmetic to algebra), consolidation (e.g., algebra with geometry), logical methods, and the increasing use and invention of symbolic apparatuses dominate. But until this stage is reached, a good argument can be given for the thesis that mathematics is a language.

Modern mathematics has grown and diversified to such an extent, however, that it can no longer be considered a language. By some natural scientists, as well as the engineer who uses many mathematical tools, mathematics might understandably be considered a language from an operational standpoint (although in modern physics, for example, many newly invented mathematical structures have come to play more of a conceptual than an operational role). This can be compared to the role of music in the life of a non-musician. For the latter it is a form of entertainment, while to the professional musician, and especially to the composer, music has many conceptual forms as well as artistic and esthetic values that only the musically trained can appreciate.

Mathematics as an Art

This brings us to the conception of mathematics as an art. For this there are stronger justifications than for the language concept of mathematics. Indeed, many mathematicians agree with this characterization of mathematics, and consider that their creative work is essentially an artistic endeavor. Moreover, if one compares the psychological stages of creation, say in the invention of a new mathematical structure, the development of a modern painting, and the composition of a symphony, he will find an almost identical progression in all three.

Mathematics as a Science of Structures and Relations

Most mathematicians would probably agree today that mathematics is a science of structure and relations, which has evolved from the primitive forms of arithmetic and geometry under the influence of both external cultural and internal growth stresses. As such, it has acquired many humanistic qualities which qualify it both as a language and as an art, depending upon the uses made of it. Moreover, many have argued for seizing the opportunity to bring out, in mathematics teaching, those features of mathematics which can contribute to the inculcation of many of our cultural values (Richardson 1952).

In a brief commentary such as this, it is impossible to give a complete justification of the statements made above. Consequently, a teacher not already familiar with them is urged to investigate them more thoroughly in the literature. He will inevitably have students, even among those whose future uses of mathematics will be purely technical, who would benefit by knowing something of the cultural aspects of mathematics. It is deplorable to allow a student to spend years in precollege and college mathematics without acquiring some knowledge of its place in and significance for man's culture.

TEACHING METHODS

Very likely the beginning teacher of mathematics at the college level will not have had any courses in teaching methods and will probably be guided, or at least strongly influenced, by the following factors: The methods used by the teachers who most impressed him during his studies; his own feelings about how he would like to have been taught the subjects that he is now teaching to others; and his intuition regarding the best way to "get through" to the particular students he is now facing.

These factors are not independent, since each has an influence on the other two, depending upon the teacher's past experiences. For example, it is possible that no one of his own teachers made much of an impression on him; indeed, that the first factor may have a somewhat "negative effect, in that he may try to avoid the monotonous teaching to which he was subjected. If he has been so fortunate as to sit under an inspiring teacher, he may do well to consider adopting as many of the latter's methods as possible.

Since the new teacher is usually quite close tohis own student days, he will probably remember how he was taught the subjects he is now teaching. Even after 40 years of college teaching, this writer can still recall vividly the ways in which he was taught mathematics. In one of his courses, both the textbook and the instructor were poor, and from this experience he learned the importance of selecting suitable textbooks and avoiding certain teaching methods. From another instructor, the most inspiring of his college teachers, he learned the importance of an informal style which permits the class to interrupt for questions, to request repetitions, or to point out errors the instructor has made (everyone makes errors); also the importance of cultivating a capacity for sensing, from students' attitudes, whether the class is finding the subject under discussion interesting. It appears thatonly experience, through contacts with other people, can develop this capacity. If, in one's social contacts, he has developed the habit of watching the reactions of others to his words, then he will likely extend this habit to his teaching. For he will have built up an intuitive awareness, through such contacts, of his impact upon his listeners' receptive faculties.

One should never forget that teaching, unaccompanied by learning by the student, is hardly deserving of being called "teaching." This fact seems to be overlooked in much of the discussion of what constitutes "good" teaching. The responsibility in the teaching process is as much the student's as the teacher's, and it may be a good idea now and then to remind the student tactfully of this fact. It would be interesting to know how much of the current student agitation for more inspiring teaching takes this into account. The person who teaches a subject to himself learns automatically, but many college students fail to understand that, as Plutarch said, "The mind is not a vessel to be filled, but a fire to be kindled." It is the teacher's task to kindle this fire.

SOME GUIDELINES

On the basis of his many years of college teaching, this writer has found that the following principles, or guidelines, are of basic importance to the teacher of college mathematics:

(1) Never introduce a new concept without first motivating it.--Many textbooks do this, but wherever a textbook being used fails to do so, the teacher should use his lecture time to provide for the proper motivation.

A good example is to be found in teaching the mathematical induction principle. If the principle is stated in full, then explained, and followed by showing how it is used as a method of proof, the teacher may expect the average student to be frustrated and to come up with questions such as "How can I find the (n+1)st term?" which have nothing to do with the principle intrinsically. Instead of proceeding in this way, the teacher should make use of what the student already knows--in this case how to count with the natural numbers. From this knowledge, he can be led to discover the mathematical induction principle for himself, in the process he will develop an intuitive feeling for it, and will then have little difficulty applying it (Wilder 1967).

The real challenge comes when the teacher cannot readily recall an experience common to all his students (such as knowledge of counting) upon which to rely. In a "scientifically" planned curriculum, embracing both elementary and secondary school curriculums and arranged with a view to anticipating future topics to be handled in their proper place, the teacher should have no difficulty. In its evolution, mathematics grew through the creation of concepts for which already known concepts provided a motivation. The new elementary school curriculums of today usually introduce intuitive geometric notions, so that when the student begins to study geometry seriously, he is better prepared with material upon which the teacher can build. Nevertheless, even with the best designed curriculums, situations will occur where the teacher must himself build up an adequate motivational background in the students; and this can tax his ingenuity severely. The challenge may prove exciting, however.

(2) Be honest.--One should never pretend knowledge of something that he doesn't really know. It is dangerous to do

so; moreover a class will usually respect and sympathize with a teacher who admits that he does not know the answer to a question and explains why. Indeed, such an event can often be turned to benefit if one encourages the students to find (or preferably, help him find) the answer. This may build initiative in the students, which will in turn help to create interest.

There is an exception to this principle, and this relates to a pedagogical "trick." It is sometimes advantageous for the teacher to pretend that he does not know the answer to a question in order to influence the class to help him work out the answer. Someone in the class may suspect the truth, but if so, will usually recognize the psychological aspect so that no harm will result. Indeed, it will likely happen that when the teacher really does not know the answer, the class will credit him with knowing it, under theimpression that he is using the "trick."

(3) Don't overprepare.--The instructor should, of course, prepare topics that are to be taken up in class. On the other hand, over-preparation in the teaching of mathematics may lead to dull lecturing and to class interruptions that may prove disruptive to a new teacher. Today's more agressive type of student is very likely to reject being "lectured at" and to want the right to join in the discussion of a topic. Preparation should consist chiefly of refreshing one's knowledge of a topic. But in presenting the topic in class one should stimulate the class to participate as much as possible in its development. Above all, the teacher should not state a theorem by raising questions which the theorem to be stated is supposed to settle; then help theclass to "discover" the theorem. Only then should the proof be worked out. Notice the words "worked out." It is well known that first proofs of a theorem are usually clumsy; only later are elegant proofs found--this is true even of the work of the best research mathematicians. After a valid proof has been worked out in class, it is permissible for the instructor to give the most elegant proof known to him--after explaining, however, that the first, clumsier proof was quite the natural thing to find, and not an indicative of the class' inferiority.

If the end of the class hour is so near as not to permit time to work out a proof, then the teacher might be wise to defer it to the next class hour, at the same time encouraging the class to think over the theorem and its implications, and to consider how one might go about finding a proof. Sometimes a student will have a proof at thenext class meeting.

(4) Don't be afraid to follow up a diversionary topic if it is brought up by the students.--If this principle is

not observed, the students may become antagonistic both to the subject matter and to the instructor. There are exceptions, of course. If the topic brought up is too special and not likely to be of general class interest, then it is just as well to tell the questioner that he may discuss it with the teacher outside of class (and explain why). Or if the topic will more logically be taken up later, the teacher may explain that to the class.

Many courses, particulary at the freshman and sophomore levels, are supposed to cover a specified list of topics. With a little ingenuity, however, this can be done even though digressions are allowed. In some departments, the beginning instructor may be given a schedule to be followed, in which each topic is allowed a certain number of hours, and the order of the topics is rigidly outlined. This practice not only is pedagogically bad, but also ignores differences between both classes and instructors. Usually the purpose is to make the instructor keep up-to-date as well as to allow for uniform examinations in all sections of a course at specified periods (although the schedule is usually handed to the instructor under the guise of "helping him!"). The worst feature of this practice is that it ignores the maxim, "Better do a few things well than many things badly." Differences in classes inevitably make it preferable to be flexible in allotting time to topics.

(5) Beware of lapsing into drill methods.--In the terminology of Professor Axelrod's article, don't be a "Type A" teacher. Mathematics is one of the subjects easiest to teach badly, since it is so symbolically oriented that it tends to allow what the writer calls "symbolic reflex" teaching (Wilder 1950). This is the kind of teaching one uses for "dumb" animals; the animal has no inkling of the conceptual aspects of a symbol--he merely learns to react to the symbol in a way that avoids disapproval or pain. But human beings can use symbols creatively; they assign the meanings to the symbols--something which so far as has ever been ascertained, no animal other than man can do. (The statement applies to college teaching, of course, not to teaching a child when he is just being introduced to language.) Consequently one should teach in such a way as to encourage symbolic initiative. Usually the person who "hates math," or who "learns" proofs (a common error for the student of geometry) has been the victim of symbolic reflex teaching.

Frequently it is stated that "mathematics is an activity; mathematics is doing mathematics." This has much truth in it when properly interpreted. It does not mean drill, except insofar as manipulative skill must be acquired as in playing the piano. The best pianist from the standpoint of technique may be rated poorly as a musician. Unless combined with exceptional interpretative skill and conception, faultless manipulation of difficult passages of music is not impressive. So, too, in mathematics, the ability to compute is not, as a rule, indicative of mathematical competence; some of the best mathematicians have been wretched computers. Manipulative skill cannot be ignored in such a highly symbolic subject as mathematics, and indeed, must be acquired; but it is a means to an end, and it is the end that is important. (Professor Boulding's remarks under his "Query Seven" are apropos in this connection as well as his remarks under"Query Six".) It is to be hoped that some of the new programing and computer methods may take over most of the teaching of manipulative skills, leaving class time for background (motivational) and conceptual aspects of mathematics.

(6) Maintain enthusiasm for mathematics.-- For one who has research interests, this should be no problem. One must be careful, of course, not to allow research time to impinge on time which should be devoted to teaching tasks. Mathematicians have a debt to their successors and to society to pass on thetorch of learning they have been handed. Moreover, every research mathematician will agree with Professor Boulding's remark, "Every good teacher learns as he teaches." This is true not only in courses closely related to one's own special field of research, but to seemingly unrelated elementary courses. Some of the most unexpected bits of wisdom, which throw a new light on some mathematical topic (not necessarily the one being taught), will pop into one's mind either during his own search for the best mode of presenting a concept or during class discussions.

If one does not have research interests, there are still many ways to keep alive his enthusiasm for mathematics. One of these is browsing in the large literature which is becoming available in the way of new expository books and articles.

Back numbers of such journals as the American Mathematical Monthly contain much expository material, as well as interesting teaching hints. Mathematical Reviews, in addition to carrying abstracts of articles in all branches of mathematics, covers new discoveries in history, logic and philosophy of mathematics; the exciting discoveries which have been made in the last decade are all recorded in this journal. Attendance at professional meetings, such as those of the Mathematical Association of America, will well repay the effort and expense involved by affording opportunity for establishing contacts with others having interests similar to one's own, and for hearing outstanding speakers. In his reading, the teacher should be alert to detect items of import for his own mathematical interests. He may find that he has a knack for introducing unusual and novel slants in some areas of his teaching, and ultimately be moved to incorporate some of these in either a journal article or a new textbook. There is always room for originality in mathematics at every level and the excitement of fostering one's abilities in this direction can be a fine incentive to inspiring teaching.

(7) Be receptive to questions of a general nature.--One of the most disturbing questions for the beginning teacher is, "What good is this?"--usually asked by a student who is determined not to waste time studying topics of no apparent use to him. Paradoxically, "this is usually of fundamental importance for an understanding of what is to come later, and often of significance to the entire development of the subject being taught. However, the student's idea of mathematics is usually as an algorithmic tool; anything of value must be something that would enable one to grind out a numerical "answer." But the student has a right to an explanation--today he may demand it! In such situations, the teacher's best "defense" is in his own knowledge and appreciation of theposition of the questioned topic in theoverall development of the subject. Moreover, the studentis perhaps affording the instructor a golden opportunity not only to "get outside" and take an appraising look at the subject, but also to expand upon the relevance of mathematics to our culture. This is an incidental way in which the desires of students to participate in the examination and structure of course content, mentioned by Professor Shamos, may be satisfied. Since mathematics, contrary to popular belief, is not an absolute science, but allows considerable arbitrariness in its content, it is not so much bound by the statement "opinion is less important than evidence" (see Shamos this volume) as are the natural and social sciences. It therefore affords an excellent opportunity for student participation in course content (as well as a challenge to theinstructor to defend the choice of topics in a course)--something which has increasingly become common in graduate courses bordering on research frontiers.

(8) Make clear the role of definition in mathematics.--Much of what one will be teaching will involve defining concepts. Some of these concepts will already be part of the student's mental equipment, but only in an intuitive sense. One of the teacher's tasks will be to make use of this intuition while at the same time making clear why mathematicians nevertheless have to define concepts. (Compare (1) above).

Explaining this to the student will go far toward explaining the general nature of mathematics.

(9) Get to know students individually as much as possible.--This has become more difficult as the number of students has increased, and compelled colleges to resort to large sections and to the use of assistants. The more aggressive students see that they do get to know the teacher, but unfortunately some who need counsel most will hesitate to seek it. The latter students run the risk of extreme frustration and of eventually dropping out. As the teacher becomes more experienced, he will be better able to detect such students.

(10) One final guideline: Avoid teaching "at" the students.--Rather, consider learning-teaching as a joint enterprise, in which the teacher's part is that of guidance by a well-informed mentor (see (3) above). Like any mentor, a teacher is not infallible--and neither, for that matter, is the subject he is teaching; its limitations and arbitrariness are being revealed at long last by modern research in logic and foundations.

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